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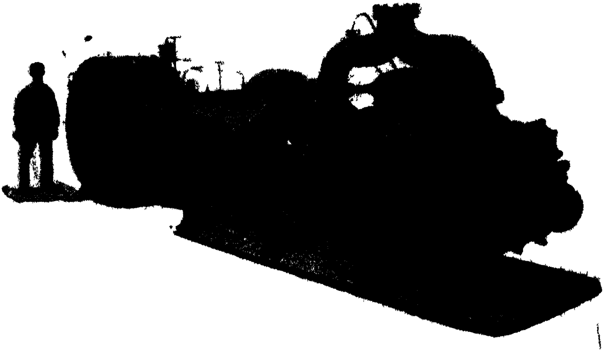

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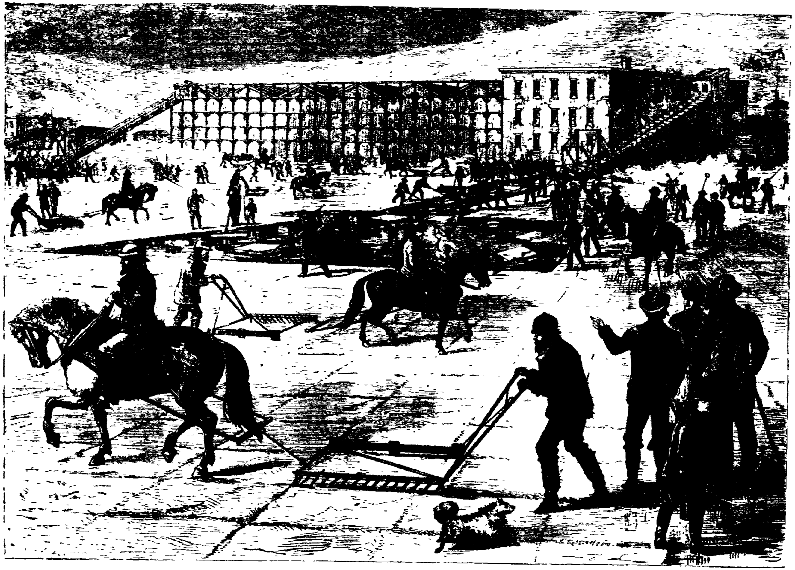

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AN ELEMENTARY HANDBOOK

BY

BERNARD H. SPRINGETT

EDITOR OF "ICE AND COLD STORAGE"

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PREFACE

THIS work has been prepared in order to provide a sufficiently comprehensive while necessarily concise handbook on the refrigerating industry, which has proved itself of such world-wide importance since the part it played in winning the Great War has become more fully known. In the present compilation the object has been to present to the general reader, as well as to the untechnical user of refrigerating machinery, sufficient knowledge as to the first principles of artificial refrigeration, while avoiding the mass of technical terms, formulae and descriptions of machinery and methods which are inseparable from the usual publications on the subject, excellent and important as these are to those able to appreciate their contents.

No attempt has been made to differentiate between the many excellent, well-constructed standard types of refrigerating machines made by various English firms of engineers, or to mention machines supplied by foreign makers. Only machines and appliances of special design or construction are separately mentioned, except when some special feature has needed enlarging upon. This handbook is intended more for the owners and users of small refrigerating plants, and the general student desirous of becoming acquainted with the elementary principles of the production and application of artificial cold.

The editor freely acknowledges his indebtedness to the authors of the following excellent text-books on refrigeration : *Refrigeration* (Prof. Wemyss Anderson) ; *Refrigeration, Cold Storage and Ice-making* (Wallis-Taylor) ; *Machinery for Refrigeration* (Norman Selfe) ;

Compend of Mechanical Refrigeration (Siebel) ; *Elements of Refrigeration* (Greene) ; *Audel's Answers on Refrigeration ; History of the Frozen Meat Trade* (Critchell & Raymond). Also to the following makers of refrigerating machinery or appliances, who have been good enough to supply illustrations for this work—

Messrs. The Audiffren Singrun Refrigerating Machines, Ltd. ; Wm. Douglas & Sons, Ltd. ; The "Empire" Direct Expansion Co. ; J. & E. Hall, Ltd. ; The Haslam Engineering Co., Ltd. ; The Lightfoot Refrigeration Co., Ltd. ; Ransomes & Rapier, Ltd. ; and John Straiton & Sons.

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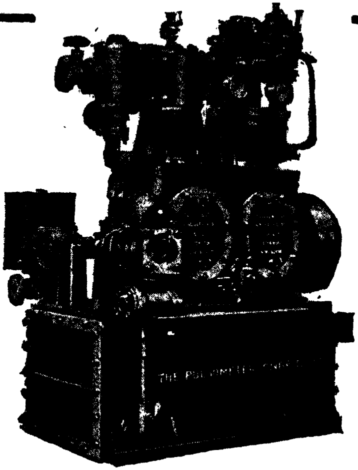

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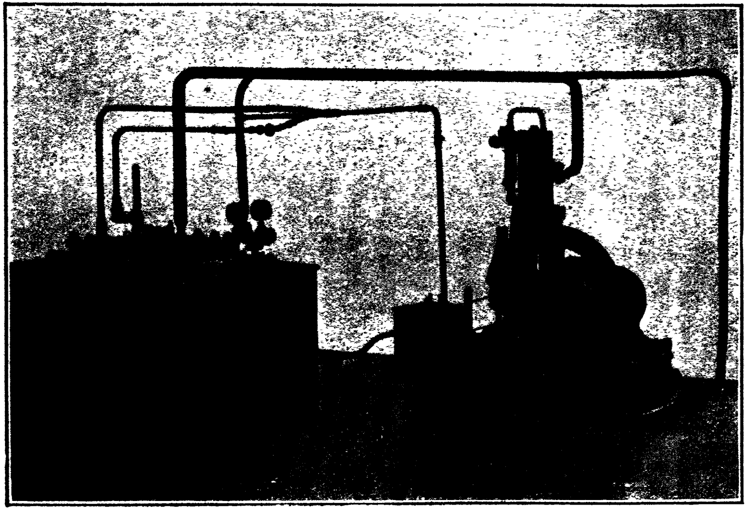

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COLD STORAGE AND ICE-MAKING

CHAPTER I

INTRODUCTION

WITH the leading part which refrigeration is universally acknowledged to have played in the Great War, fresh in the minds of the whole world, it is a fitting opportunity to endeavour, in a more popular method than has been adopted in previous books on the subject, to place some more important features of this most highly-developed modern industry before the mind of the ordinary student, who is not seeking to add to already acquired technical knowledge, but to ascertain the root-principles of ice-making and cold storage, together with a wider conception of the innumerable other industries in which refrigeration is now an integral part.

The practice of cooling bodies below the temperature of the surrounding atmosphere has been followed for ages, thus giving us the elementary principles of artificial production of cold. But the use of natural cold for the preservation of food is centuries older still. Without considering for a moment the fact of a mammoth being accidentally enclosed in a mass of ice many thousands of years ago, possibly in the Glacial period, and its flesh remaining perfectly good for human consumption after all those ages, and being eaten without any ill effect by testing scientists whose eagerness overcame perhaps any ordinary scruples as to a source of origin, it is a well-recognized fact that caves retaining natural cold all the year round practically, ice-bound recesses in the mountains, snow-banks in gloomy, sunless valleys, were largely made use of by the ancient inhabitants of all countries for storage of food for future needs, even as the Greenlander at the present day makes use of lumps of snow to preserve his stores of seal flesh during the short summer of the extreme North.

The earliest method of cooling practised, still to be met with in India, Mexico and other warm climates, was by evaporation, the liquid to be cooled being placed in porous vessels and, percolating through these, cooling that which remained inside. Nor can ice-making be claimed as entirely a modern achievement. Ages ago, in India, like China, Mexico and Peru and that lost Atlantis which so evidently was a connecting link between these lands of pre-historic advanced civilization, water was frozen in shallow, porous earthen dishes, resting on some non-conducting material, such as straw or grass, by being exposed to currents of air during the night, when a thin film of ice formed on the surface.

Another method of abstracting heat and producing cold, that has been known and practised for many centuries, is by dissolving saltpetre in water, or mixing common salt with ice or snow. By this means anything immersed in the resulting liquid was cooled to a very low temperature, or if desired to a freezing one, just as ices and ice-cream are still produced at the present day, where mechanical refrigeration is not employed for more rapid production on a larger scale.

The use of such frigorific mixtures for the abstraction of heat (which, as will be shown later, is the actual form of production of cold), many forms of which are still set out in works on chemistry, was known as far back as the year 1607,' and the most common combination, that of ice and salt, is said to have been used by Fahrenheit in 1762, when he placed the freezing point of water at 32°, the limit of negative temperature.

The production of cold by what may be termed mechanical means, that is, by the use of a refrigerating machine as distinguished from chemical action, is of much more recent date. It was found, in the early part of the eighteenth century, that evaporation of a liquid would take place if the pressure were removed, particularly if the liquid were ether, or some other highly volatile fluid. This evaporation would occur at such a low temperature that ice would rapidly form on the surface of the vessel containing the boiling liquid if the vessel were placed in water. It was also found that if the vapour arising from the evaporation of the liquid were compressed to a higher pressure than that at which evaporation took place, it could be condensed again by water of ordinary temperature and the process repeated.

Dr. Cullen is said to have made a machine for evaporating water under a vacuum in 1755, and Lavoisier experimented with ether in France shortly after, but the more important progress appears to have been made about the beginning of the nineteenth century. In 1810 Leslie experimented with a machine using sulphuric acid and water. In 1824 Vallance, no doubt taking his idea from the evaporative system so long used in India, as mentioned above, took out a patent under which dry air was circulated over shallow trays of water, when evaporation took place and heat was abstracted. An improvement on this system was patented in New South Wales in 1858 by G. B. Sloper, in which the water to be frozen was placed in canvas bags, so that the whole surfaces of such vessels were exposed to the evaporative effect of the surrounding air as well as the surface of the water itself. A machine to work this process was constructed and tried commercially but without success, owing to the excessive amount of power required to produce a given result, which might have been easier attained in all probability had the knowledge of thermodynamic laws at that time been as widely extended as it is in our own day.

In 1834 Hagen experimented with the volatile spirit of caoutchouc, and in the same year Jacob Perkins of London constructed the first ice-making machine which worked successfully with a volatile liquid ; this machine, which was patented in August, 1834, was the forerunner of all the compression systems of the present day. In this machine ether was vaporized and expanded under the reduced pressure maintained by the suction of a pump, and the heat required for such vaporization was abstracted from the substance to be cooled. The resulting vapour was then compressed by the same pump into a vessel cooled by water, until, under the influence of the increased pressure, the vapour, parting with heat to the cooling water, again condensed to a liquid, and the liquefied medium was then ready to be evaporated and expanded over again.

It will be seen from the accompanying illustration (Fig. 1) of Jacob Perkins's machine, taken from the application for the English patent, that it included the four principal features still in use in all modern compression systems, viz., the evaporator, the compressor, the condenser, and the expansion or regulating valve between the condenser and the evaporator.

But the original inventor does not seem to have had any more success in introducing his machine for commercial purposes than his predecessor Vallance.

In 1845 Dr. Gorrie brought out the first cold air machines, in the improvements upon which we meet with the since world-renowned names of Windhausen, Bell, Coleman, Haslam, Hall, Lightfoot, Giffard and others. The cold air machine was the first one successfully employed in bringing meat from Australia to Europe.

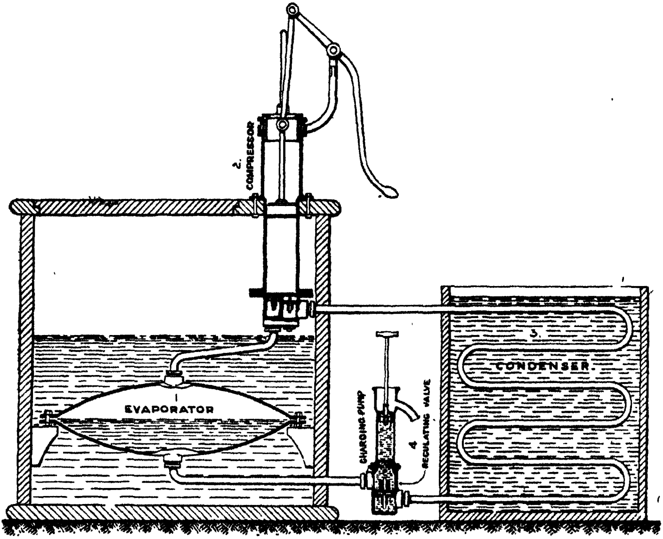

FIG. 1

THE FIRST PERKINS ICE MACHINE. FROM THE APPLICATION FOR THE EARLIEST PATENT.

In 1850 Carré invented the ammonia absorption process, with which are intimately associated, in this country, the names of the original firm of Pontifex & Wood and its subsequent incorporators, the Farringdon Works, London, and the Haslam Engineering Co., of Derby. Some excellent machines on the absorption system were installed by all three firms, and gave good results in working. But the excessive space required was an objection. The system is still largely used in the United States with improvements on the original Pontifex designs, but in this country they have been largely superseded by the more compact compression machines.

Between 1850 and 1860 many improvements were effected, in England, America and Australia, in the Perkins ether machine. Prof. Twining of Ohio, and James Harrison of Geelong, both experimented freely in such improvements. The former is said to have had a machine working successfully between 1855 and 1857, and Harrison in 1855 produced, in Victoria, fish frozen in the centre of a block of clear ice. The original Harrison machine was made as a double-table engine, with four slide valves to the ether pump, a separate inlet and outlet valve on the top and bottom covers being worked by cams and an eccentric. Several of these machines were supplied and gave good satisfaction to the purchasers.

Meanwhile the Harrison machine had been introduced into England by Messrs. Siebe & Co., the predecessors of Messrs. Siebe Gorman & Co., so long associated with the manufacture of diving apparatus for admiralty and commercial use in almost every country in the world. It is usually admitted that Messrs. Siebe installed the first absolutely successful machine for manufacturing purposes, which was used for the extraction of paraffin from shale oil in Scotland in 1861. Immense interest was aroused by the installing of an ether machine by Messrs. Siebe in the Great International Exhibition in Hyde Park in 1862, under the charge of the late Mr. H. J. West, whose name has since been so closely associated with the manufacture of refrigerating

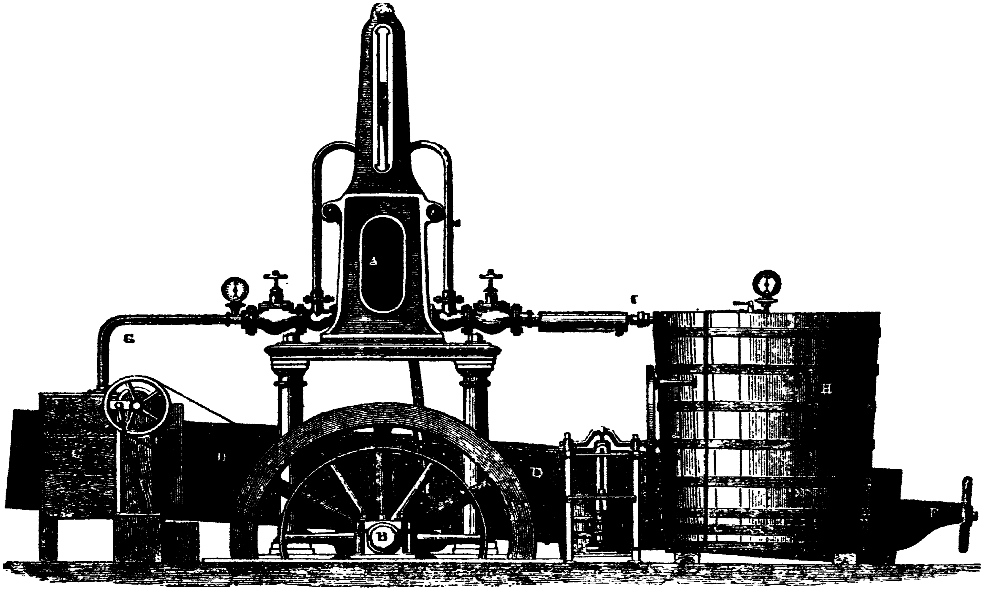

FIG. 2

HARRISON ETHER MACHINE, EXHIBITED IN 1851 BY SIEBE & CO. A—DOUBLE-ACTING AIR PUMP; B—REFRIGERATOR; C—ETHER COOLER; D—SELF-ACTING DELIVERY VALVE; E—ICE-MAKING TANK; G—CENTRIFUGAL PUMP machines of various types, and the firm of which his son Mr. Ernest West is the head, still supplies these ether machines, of course greatly improved in design though on the original Harrison principle, for purchasers in India and other hot climates, where it is difficult to obtain condensing water of low enough temperature for the economical employment of other refrigerating mediums. The ice-making plant operated at the Exhibition made 1 ton of ice per day, differing only from the imported American and Norwegian ice, on which consumers had up till then depended solely for supplies, in its being somewhat less transparent, as processes which have since been thought out for more closely resembling Nature in the production of absolutely transparent ice had not then been introduced.

Siebe machines capable of making 10 tons of ice per day had by this year (1862) been supplied to the East India Government for making ice for the Indian military hospitals, and to the P. & O. Company for replenishing the ice-houses on their passenger steamers from factories established in Egypt and elsewhere further east, and to purchasers in North and South America.

Two ice-making machines on the Carré system (ammonia absorption) were shown in operation at the same Exhibition, a small one for making 10 or 12 lbs. of ice for domestic use, and a large one for commercial use, whose actual capacity does not appear now to be known. It is recorded, however, in engineering journals of the day that whereas the Carré machine was supposed to produce 100 lbs. of ice by the combustion of 1 lb. of coal, in actual practice it only produced at most 19 lbs. of ice to 1 lb. of coal, or its equivalent in other fuel.

Another early experimenter was Charles Tellier, whose name is held in respect throughout the world, not only as the father of refrigeration in France, but as the first one, after repeated experiments and several failures, to be successful in bringing frozen meat across the ocean. Tellier employed methyllic ether as his refrigerating medium, and an illustration of his earliest machine is reproduced in Fig. 3, on the following page.

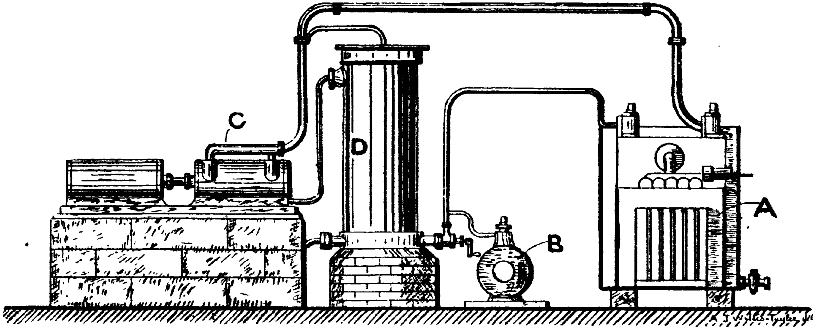

FIG. 3

TELLIER'S ORIGINAL METHYLLIC ETHER MACHINE

CHAPTER II

TERMS USED IN MECHANICAL REFRIGERATION

BEFORE proceeding to discuss the various types of refrigerating machines, and the innumerable applications of mechanical refrigeration at the present day, it will be as well to mention as briefly as possible the various terms used in connection with the science and practice of refrigeration.

A HEAT UNIT is a standard of measurement by which is expressed the capacity of a given weight of any body to absorb and retain heat or energy under a given increase of sensible heat or temperature. As water possesses a greater capacity for heat than almost any other known body, its properties have been adopted for such a standard.

A CALORIE, or metric heat unit, is employed in France, and in purely scientific work, to express the equivalent of the amount of heat required to raise the temperature of 1 kg. of water (2·2 lbs.) through 1° C. (1·8° F.) at its maximum density temperature of 4° C., *i.e.*, raise it from 4° to 5° C. Dr. Joule, after numerous experiments, determined that when mechanical energy is converted into heat the amount of heat produced is proportioned to the mechanical energy expended, and, specifically, that 1 calorie represents 424 kilogrammeters of energy.

A BRITISH THERMAL UNIT (written B.T.U.) is the universally recognized standard of heat measurements amongst refrigerating engineers in England, America and Australia. It represents the equivalent of the amount of heat required to raise the temperature of 1 lb. of water through 1° F. at its temperature of maximum density, *i.e.*, from 39° to 40° F. This Dr. Joule found to be equivalent to 772 ft.-lbs. of work. More recent experiments have led to the adoption of 778 as a more accurate equivalent. One calorie is equivalent to 3·96 B.T.U. when comparing estimated capacities of refrigerating machines.

SPECIFIC HEAT, or capacity for heat, is the relative capacity of any substance for heat, water being usually taken as the standard, and it has the greatest heat of substances in common use. One lb. of water requires 1 B.T.U. to raise its temperature 1° F. One lb. of cast iron only requires 0·13 B.T.U.; the specific heat of cast iron, *i.e.*, its relative thermal capacity, is therefore spoken of as being 0·13. The specific heat of gases varies in a different manner. Under a constant pressure a gas will expand if heated, and the specific heat under these conditions is found to be different when the gas is confined, and so kept at constant volume, the pressure increasing. The specific heat of ice is 0·504; of air 0·4805; of oxygen 0·21751; of nitrogen 0·24380; of hydrogen gas as high as 3·409; of anhydrous ammonia 1·020; of carbonic acid 0·980.

The average specific heat for unfrozen materials brought into a cold store may be taken as 0·80, and half of this, 0·40, after freezing.

LATENT HEAT is the amount of heat that must be supplied to any body to change it from a solid to a liquid, or to a liquid to change it to a gaseous state. This amount of heat is called its latent heat, and is expressed in thermal units. Thus we have in the melting of 1 lb. of ice a latent heat of 142 thermal units, and we understand by this that in order to melt 1 lb. of ice it must absorb into itself, in making the change, 142 B.T.U., or the equivalent of 1 lb. of water changing 142° F. or 80° C.

The heat required to change a solid body into a liquid is known as the *latent heat of fusion ;* to change a liquid into gas is known as the *latent heat of vaporization.*

REFRIGERATING CAPACITY. The capacity of a refrigerating machine is expressed in "tons of refrigeration" ; that is, the number of thermal units required to melt 1 ton of ice is described as 1 ton refrigerating capacity. Allowing for losses of all kinds, it may be assumed that 1 ton refrigerating capacity is equal to freezing 1 ton of miscellaneous goods, and retaining them at any desired low temperature.

ICE-MAKING CAPACITY is usually taken as being half the refrigerating capacity ; *i.e.*, a machine described as of 1 ton capacity per 24 hours will supply sufficient cold to produce ½ ton of ice in the same period.

INSULATION is the method employed in constructing a cold store or an ice factory to keep out as much as possible of the outside air and at the same time retain as much as possible of the cold air supplied through the refrigerating machine, and so lessen the amount of energy required from the machine in maintaining a desired low temperature. It will be seen, therefore, how much depends upon the selection and use of a reliable insulating material, at the same time best suited to the exact purpose for which it is required. A separate chapter is devoted to this important subject.

ABSOLUTE ZERO is, in the Centigrade scale, the melting point of ice, while in the Fahrenheit scale it is taken as the temperature obtained by mixing salt and ice. Thus 0° C. is equal to 32° F. But although 0° F. is thus considerably below the freezing point of water it does not imply that this is the lowest temperature that can be reached. We have to descend to —312°F. to reach the liquefying point of air, and experiments with liquid air are frequently conducted at a temperature considerably lower even than this.

CHAPTER III

PRINCIPLES OF MECHANICAL REFRIGERATION

REFRIGERATION has been defined as the process of cooling, performed artificially or mechanically by transferring the heat contained in one body to another, thereby producing a condition commonly called cold, but which is in fact an absence of heat. This transfer of heat is most rapidly and economically accomplished by evaporation.

In the ancient way of producing cool liquids, the evaporation which took place at the outside of the porous vessel in which the liquid was placed required heat, and this was largely supplied from the liquid within. The liquid was cooled by the removal of heat. If this removal of heat cools the liquid to its freezing point (fusion point of solid), any further evaporation of the liquid from the surface of the vessel would remove heat from the liquid and cause some of it to solidify, forming ice if the liquid were water. In the case of salt being dissolved, this same kind of energy is needed. In this case it is called the heat of solution. To change the condition of the molecules of the salt, so that the molecular forces are overcome, energy is applied, and, as this energy comes from the liquid, its temperature is lowered.

It is necessary that we should consider certain simple elementary laws of dynamics, the first being—When heat is transformed into mechanical energy, or mechanical energy transformed into heat, a certain definite relationship exists which is expressed as the mechanical equivalent of heat, or " Joule's Equivalent." The second law has been expressed in various ways, of which Maxwell gives us one of the best definitions : " Admitting heat to be a form of energy, the second law asserts that it is impossible, by the unaided action of natural processes, to transform any part of the heat of a body into mechanical work except by allowing heat to pass from that body into another at a lower temperature."

As an analogy, to quote Prof. Wemyss Anderson, water in an elevated reservoir cannot do work unless it is allowed *to pass* to a lower level. In the reservoir it represents so much potential energy. A heated body contains an amount of energy (potential), but unless the heat is allowed to fall to a lower level aided by a suitable machine, no work will be done.

Again, a body may contain a large quantity of heat, but if it is at the same temperature as its surroundings the heat cannot be made do work, because it cannot change its level, *i.e., it is not available.*

It is not every thermal unit that can be transformed into work, and we must bear in mind that, according to Lodge, " energy is only useful when transferred—it is during transference of energy that work is done, hence any condition that prevents or lessens the transferability of energy prevents or lessens the performance of work by means of it, *i.e.*, makes it more or less useless."

Clausius gives the second law in a manner that appears peculiarly applicable to refrigeration : " It is impossible for a self-acting machine, unaided by any external energy, to convey heat from one body to another at a higher temperature."

This, in common with other definitions of the second law, places a limit to the fall of the temperature in a body doing work by pointing out that it actually requires *work* to be expended, " external aid," to convey heat from one body to another at a higher temperature, in other words, to make a body colder than its surroundings. But work, in the form of an ice-making or refrigerating machine, even of unlimited power, is unable of itself to produce cold, or make ice from water. It is simply an instrument for dealing with some substance which operates as a medium in such a way that it (the medium) is enabled to take up heat from the body to be cooled and transfer it to another body. As a rule this heat is transferred to the water which is used for the purpose of condensation and goes to waste.

There are two distinct systems of mechanical refrigeration in use, both operating by means of a medium. Under the more simple system this medium is a permanent gas, which is alternately compressed and expanded, but not liquefied under such compression. In actual practice atmospheric air is alone used for this purpose, and the machines are termed compressed air machines.

Under the other system of mechanical refrigeration, that more generally employed in the present day, a more volatile medium is employed, and in the operation of the machinery there is alternate liquefaction and volatilization. Although many different media have been tried, each of which has some special quality to recommend it, the principal ones to which reference will be made are ammonia, carbonic anhydride, sulphurous acid and ether. In the system introduced by Carré a solution of ammonia in water is employed, the gas is driven off by the direct application of heat, and is again reabsorbed by the water after fulfilling its functions in the circuit of the apparatus. This is known as the " Absorption System," and though many authorities still advocate its advantages, the greater number of refrigerating engineers have for many years, especially in this country, adopted the compression system.

Both in theory and practice compressed air machines require very much more power for a given abstraction of heat, amounting to from four to six times as much as some other machines need. From the nature of their construction also they occupy much more space, a very great consideration on board ship, for which use they were employed very largely in the early developments of the transport of frozen meat. In addition to the greater space taken up by this type of refrigerating machine, the effect of the moisture in the atmosphere of the refrigerating efficiency was a further disadvantage. The compressed air machine has therefore been practically superseded by the compression machine, even by the firm whose name will always be so closely associated with the manufacture of cold air refrigerating machines, the Haslam Engineering Company, carbonic anhydride machines being chiefly installed on board ship, while ammonia compressors have largely taken the place of cold air machines in cold store installations.

In the compressed air machine the air is first compressed, during which process heat is generated. This heat is abstracted in an apparatus similar to a condenser, which is, however, an incorrect designation for the simple reason that no condensation of the medium is produced. The refrigeration of the air is the result of allowing the compressed air to re-expand while doing work. This re-expanded air is reduced in temperature and circulated in the refrigerating coils, as in other systems, to perform the refrigerating duty required. The principle of thermo-dynamics involved is that when a gas is equivalent in mechanical energy to the work done. When the air is compressed, the amount of heat generated is equivalent in mechanical energy to the amount of compression. In practice, of course, the usual inevitable losses attendant upon any transformation of energy tend to reduce the value of the effective results.

The essential parts of a compressed air plant are as follows—

A *Prime Motor*, as a steam engine, as a source of motive power;

A *Compressor*, which compresses the air;

A *Cooling Apparatus*, consisting generally of a coil of pipe containing the compressed and heated air, arranged so as to be cooled by a flow of water;

An *Expander*, consisting of a cylinder, piston and valves, arranged similarly to those of a steam engine, with a cut-off into which the cooled compressed air is admitted during a portion of the stroke, the air acting expansively during the remainder of the stroke, and thereby being reduced in temperature. On the return stroke this cooled air is expelled from the cylinder, and received into

A *Refrigerator*, the last of the series, consisting of coils of pipe, arranged as in refrigerating plants generally to produce the results desired.

From the refrigerator the air passes again to the compressor, to be again started through a repetition of the cycle of operations just enumerated. For successful operation there must also be included traps for the separation of oil and snow from the cold air, and for separating moisture from freshly-supplied air, and provision for water-jacketing the compressor cylinder. The piston-rod of the expanding cylinder may be connected through a connecting rod to a crank on the main shaft, so that the work of the expanding air is used to assist the steam in operating the plant.

Refrigeration may also be produced by releasing the cooled air direct into the chambers to be cooled. In this case, the air is drawn from the refrigerator chambers by the compressor. This system was at one time extensively used on board ship, but considerable difficulty was encountered from the snow formed in the apparatus by the condensation of moisture contained in the air.

When a volatile liquid is employed, as in the ordinary compression refrigerating machine, the system is the same whichever particular medium may be employed as the refrigerant. Taking ammonia as an example, the whole accompanying diagram (Fig. 4) gives a useful elementary illustration of the whole cycle of operation. A compressor *A* relieves the pressure in the coil *B* by drawing vapour from the coil, since the coil is connected to the suction side of the compressor. The vapour thus removed is compressed by *A* and delivered under pressure into a condenser coil *C*. The vapour will be compressed in *C* until the pressure is such that the temperature of saturated ammonia vapour at that pressure is slightly higher (about 10° or 20°) than that of water coming from the supply *D*. When this pressure is reached, the water, having a lower temperature than that of saturation of the ammonia, will abstract heat from the ammonia and cause it to condense so that liquid ammonia will flow into the receiver *E*. If now the pressure in the coil *B* is such that the temperature of boiling for ammonia at that pressure is above the temperature of the substance around the coil *B*, the ammonia gas and liquid in the coil will give up heat to the substance through the coil and will be cooled off, but nothing further can happen. If, however, the boiling temperature corresponding to the pressure is less than that of the substances around the coil *B*, then heat will flow from them into the ammonia in the coil and cause the liquid to evaporate, requiring the further action of the compressor to keep the pressure low enough to remove heat from the substances near the pipe. Of course, if the first condition were true, no vapour would form and the action of the compressor would reduce the pressure so that the boiling temperature would at least be low enough to remove heat from the substance. The supply of liquid ammonia is regulated by the valve *F*, known as an expansion valve. It is in reality a throttle valve, throttling the liquid ammonia from the high pressure in *C* to the low pressure in *B*. The coil *B* may be placed in a room to be refrigerated or it may be placed in a tank *G*, containing brine of a low freezing point. This brine is cooled and sent out to rooms which are to be refrigerated or to ice tanks, and after receiving the heat the warm brine is returned to the tank to be cooled again. The first system is known as the Direct Expansion system, the latter is called the Brine Circulation system. Fig. 5 is another illustration of the operation of a refrigerating machine on the compression principle.

All the media used as refrigerants in mechanical refrigeration require to take up heat to change them from the liquid to the gaseous condition. It makes no difference to this property that the boiling point of three of the four gases generally used is below the ordinary temperature of the atmosphere, so that their normal condition at atmospheric pressure is the gaseous one. As with water and steam, the boiling point of these and other gases means the temperature at which such gases will liquefy, as well as that at which their liquids will pass again to the gaseous condition, in fact a temperature under which a given weight of the material may be either entirely liquid, entirely gaseous, or partly in one state and partly in the other, depending for its condition upon the number of heat units contained in or held by

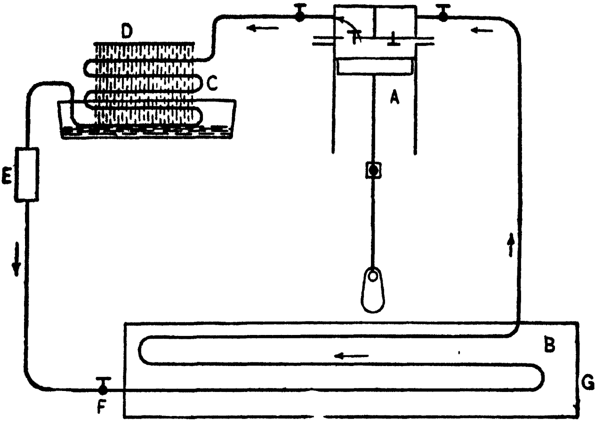

FIG. 4

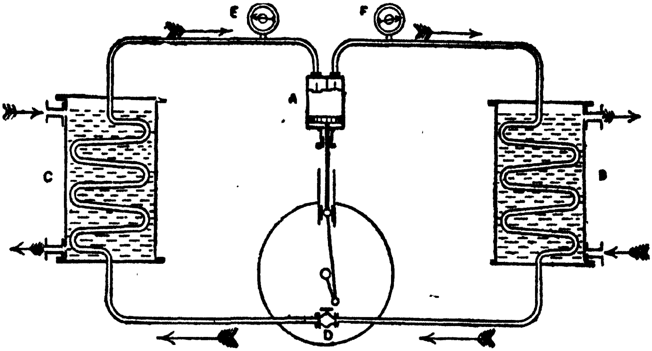

FIG. 5

DIAGRAMS ILLUSTRATING THE WHOLE CYCLE OF OPERATION OF A REFRIGERATING MACHINE ON THE COMPRESSION PRINCIPLE it ; and such temperature, as with steam, depends upon the actual pressure to which it is subjected at the time. Conversely the pressure under which any gas can be liquefied depends upon its temperature. The critical temperature of a gas is that temperature above which no increase of pressure will produce liquefaction and the gas remains permanent. At atmospheric pressure the boiling point of the four gases mentioned is as follows—

Sulphuric Ether.	*Sulphur Dioxide.*	*Ammonia.*	*Carbonic Acid.*
+ 96°	+ 14°	- 29°	- 124°

For the practical purposes of artificial refrigeration the lowest temperature to which heated gases under pressure can be reduced is limited by the temperature of the water used for condensation. This water may be as low as 45° or 50° in temperate countries, and in hot climates may exceed 90°.

Under the temperatures met with in practical work, the boiling point of these varies considerably in accordance with the pressure. For instance, carbonic acid, which under atmospheric pressure will boil at 124° below zero, requires about 1,080 lbs. per sq. in. to liquefy it at 96°, affording a great contrast to water, the boiling point of which at 14·7 lbs., or one atmosphere, is 212° and which requires the pressure reduced down to 0·089 of 1 lb. per sq. in. (or a very high vacuum) to enable it to evaporate at 32°. Again, sulphuric ether, which boils at 96° under atmospheric pressure, must be attenuated to at least 12 lbs. below atmospheric pressure before it will evaporate at the freezing point of water. From these figures it will be noted that machines for making ice by the evaporation of either water or ether must work with a partial vacuum, their pumps exhausting their refrigerators to pressure below that of the atmosphere.

CHAPTER IV

AMMONIA COMPRESSION REFRIGERATING MACHINES

THE compressor is the important part of all compression refrigerating machines, and certain general principles are necessary in its construction, whatever gas may be employed with it as the refrigerant, or whatever type or design of machine may be preferred, by any particular firm of makers.

The function of the compressor may be thus briefly described. Operated by some form of power, steam, gas, oil or electricity, the compressor draws the gas, or vapour from the evaporating coils of the refrigerator after it has performed its duty of cooling, compresses it on the return stroke of the piston and forces it into a series of coils in the condenser, in which coils, under the cooling action of water, it resumes its liquid form. High efficiency in a refrigerating plant means passing the maximum weight of gas through the cylinder of the compressor with a given expenditure of power, while the efficiency of the evaporator is measured by the evaporation of the minimum weight of the liquid medium per unit of heat abstracted.

The design and construction of the compressor cylinder with its piston and valves is of very first importance, as they are the primary instruments concerned. The shafts, cranks, connecting rods, fly-wheels, steam cylinder or other portions of the prime movers which supply the power to the piston of such a cylinder occupy, as accessories, a secondary though important part. Almost any form of compressing cylinder, good, bad or indifferent in design or construction, may have its piston driven by almost any mechanical arrangement of cranks, rods or levers, also either ill or well designed, and may also receive its motion from steam or any other power, economical or wasteful, without at all effecting its quality or efficiency as a compressor.

It is therefore desirable in instituting a comparison between different types of refrigerating machinery to classify their various functions so that they may be separately and properly compared. A well-known Australian refrigerating engineer, Mr. Norman Selfe, considers the following to be a convenient division to adopt in considering the questions involved and the conditions that should be fulfilled—[1]

Firstly.—The construction of the compression pump itself, with its pistons and valves, and its efficiency for the work it has to do.

Secondly.—The connection between the motor piston of the engine and the driven piston of the compressor, when the latter is driven direct by a steam engine, as effecting the simplicity and efficiency of the transfer of power from one to the other, and the first cost of the whole machine.

Thirdly.—The provision for minimizing wear and tear, reducing cost of maintenance and simplifying access to working parts for inspection and repair.

It has to be borne in mind that an engine piston commences its stroke with the *maximum* pressure acting upon it, which continues until the steam is shut off, when the force of power of the same diminishes by the ratio of expansion to the end of its travel; but the piston of a compressor commences its stroke with the minimum of resistance, or without having any resistance to meet and all apart from friction, because the gas is then, or should be, of equal pressure on both sides of it. The resistance of the piston, however, commences with its movement, and the pressure of the gas in front rises until the condenser pressure is reached, and then it continues uniform as it passes the outlet valve to the end of the stroke. It is not all expelled, however, in practice, because a certain amount, more or less, is left in the space between the piston and the cylinder head, called the " clearance."

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[1] *Machinery for Refrigeration,* by Norman Selfe. Chicago: H.S.Rich & Co., 1900.

This question of clearance has always been a source of anxiety to all makers of compressors, and its importance is sometimes forcibly brought home to those in charge of refrigerating plants when they see a cylinder head fly clear of the studs through having too little clearance. In other cases a very small effective result is obtained through the machine having too much clearance.

It is easy to understand that as the ratio of compression becomes greater, so much shorter is the latter part of the stroke during which actual delivery of gas takes place ; therefore, the greater the ratio of compression the greater is the loss with a given amount of clearance. If this clearance is as much as ⅛ in., then the waste or lost spaces would be from ¼ to 1 in. according to the position of the piston at the commencement of the compression of the gas, and this waste space would be deducted from the effective stroke of the piston. This shows that there would be a very large percentage of loss with high ratios of compression that would be intensified with short-stroke pistons.

In considering the qualities that are desirable, or the conditions that should be fulfilled, in an ideal compression machine the following characteristics are directly concerned with the work done on gas—

(1) On the inward or suction stroke the cylinder

should fill with gas at a pressure as little below that in the expansion coil as possible, and the outlet valve should be tight.

(2) The piston and its rod should work with a maximum of tightness in order to prevent leakage, and with a minimum of friction, which (as it generates heat and requires extra power to overcome it) involves a twofold loss.

(3) On the outward stroke the inlet valve should not permit any leakage back, and the whole contents of the cylinder, less the minimum of clearance, should be discharged through the outlet valve at a pressure at little above that in the condenser as possible.

Dealing with the general design and construction of the whole machine, and noting that the heavier foundations which are required by some compressors and their steam engines must be taken into account when comparing the cost of the same in working order—

(4) The machine—other things being equal—should be self-contained, on one sole plate, so as to be easily and cheaply erected on the minimum of necessary foundations.

Seeing that with single and double-acting cylinders of equal capacity and piston speed, single-acting machines must have double the piston area of double-acting ones, and therefore transmit double the stress to the connecting rods and cranks, then—

(5) The work of the compressor with its crank, rods and crossheads should be double-acting instead of single-acting, and the ratio of compression should be as small as possible during both strokes, in order to distribute the work over as large a portion of the crank-pin's path as possible.

If it is required to minimize the strain on the crank pins, shafts and connecting rods, and keep down the weight, cost, friction and wear of those parts, and high mechanical efficiency with low working expenses are aimed at, then—

(6) In order to minimize the friction in the bearings, and prevent the loss of power which results from indirect action, in the case of direct drive, the connection of the engine piston to the compressor piston should be as direct as possible and the crank shaft with the crank pins and connecting rods should only be required to take up and transmit the *difference* between the power exerted by the steam and that required by compressor pistons respectively, at a given position, instead of having to carry the work and friction due to the *sum* of those powers.

(7) The piston and valves should be easily accessible for examination and renewal.

In order to maintain the whole of the machine in working order—

(8) All covers or bonnets should be made with a simple joint, and, to insure perfect absence of leakage, such things as double or treble connections, with bridges under one joint face, should be avoided.

Lastly, all wearing surfaces should be adjustable and easily adjusted.

In order that the piston of a compressor should work gas-tight and yet with the least amount of friction and wear, two things are essential—

(1) Tight working, friction and wear will depend very largely on the method of lubricating which is employed. As a rule the oil used in lubricating the cylinders is intended to be carried right through the system very rapidly, in order to take up the heat of compression, and it is supplied at every stroke by means of a special pump. A certain amount of oil remaining in the bottom of a vertical cylinder prevents any gas from

escaping through the piston-rod packing, although in a double-acting compressor this oil is subjected to the full forward pressure of the gas. Certain makers claim that specially good workmanship enables oil to be dispensed with altogether for lubricating the piston, except so far as it is carried by the rod. In machines of the Linde type a pump, driven by the engine, is used to inject oil continuously between two separate packings in the packing box, to prevent the escape of gas, and some of this is carried into the cylinder at every stroke. Other machines are constructed with a lubricator on the stuffing box instead of a pump. By the injection of a certain amount of sealing oil into the cylinder at each stroke of the piston a liquid base is formed, and not only does this seal the piston, but it also lubricates the latter and the valves and prevents leakage at the stuffing box, while, owing to the small quantity of such sealing oil that is employed, the capacity of the machine is not appreciably reduced.

Where there is an oil circulating system operating in conjunction with the compressor, with a view of alleviating the high temperature effects of the cylinder walls, by absorbing a portion of the heat of compression, and thus producing the equivalent of a water jacket, there is the difficulty that the oil cannot be kept in this part of the system alone. It will be found that a large quantity of oil can be taken from the ammonia cooler each month, representing oil which has gone over through the condensers and cooling coils, thus diminishing greatly the effect of the latter. In order to obviate this as far as possible an intercepting trap, called the oil separator, is placed on the line of the discharge between the compressor and the condenser to separate the oil from the ammonia gas. This prevents the pipe surface of the condensing and evaporating system from becoming covered with oil, acts as an insulator and prevents rapid transmission of heat through the wall.

(2) It is imperative that the metal in the cylinder should be of a very hard and uniform texture. The cylinder itself should be made as a simple barrel, or as plain a casting as possible. Any complication of cores, passages, flanges or projections upon a cylinder casting has a tendency to cause the metal to "draw," or become spongy, and make it very difficult to produce a sound, solid casting from specially hard iron. What is still worse, perhaps, is that an irregular casting has a tendency to alter its shape with every change of temperature, and as a compressor cylinder is subject to more changes of temperature than a steam cylinder, the desirability of having a casting that will be cylindrical at all temperatures and which will expand and contract equally all over is very evident. Messrs. Ernest West & Beynon have obtained excellent results by the use of a solid steel block for their cylinders, turned and bored to the requisite dimensions.

The necessity of the greatest possible care being exercised in the casting of the cylinder is evident from the fact that certain compressor cylinders want reboring after a single season's work, and pistons sometimes leak after being started only a few weeks, even if they were tight at first. The power of the engine has probably been employed to wear out the machine through undue friction. The remedy for this is to have cylinders made as plain castings of hard, homogeneous metal, accurately bored and lapped, and pistons that will work satisfactorily even if there are no rings in their grooves. Piston rings are extremely useful and necessary adjuncts, but, as often made, with a very strong spring to atone for a bad fitting piston, they are simply devices to wear out the cylinder and make the fit worse. An inspection and comparison of the several sections will show which of the types is most likely to secure hard and absolutely sound castings.

Compressors are of two kinds, single-acting and double-acting, and both of these are divided again into horizontal and vertical. Broadly speaking, horizontal compressors are usually double-acting and vertical compressors single-acting. A single-acting compressor has the advantage when working with a gas of the tenuity of ammonia, owing to its only carrying the lesser pressure of the suction side over the stuffing box, of preventing the stuffing box from being subjected to the high pressure of the condenser which is unavoidable at the termination of each stroke in a double-acting compressor, thereby greatly reducing the chance of leakage. On the other hand, however, a double-acting compressor is considered more economical as it deals with nearly twice the amount of gas at each revolution of the crank shaft as a single-acting compressor of the same diameter and stroke. While the double-acting compressor has thus twice the capacity of the single for a given floor space, and there is a saving in the cost of the plant as well as in the space occupied, it requires more care in keeping the piston-rod tight, owing to the high pressure of the compression and to the extreme range of temperatures between the suction and the compression pressure.

Double-acting compressors are not considered practicable for vertical arrangement, as on their downward stroke the gas is not all expelled, owing to the fact that it is impracticable to use an arrangement of outlet and inlet valves to large waste spaces. These clearance spaces are filled with compressed gas on the downward stroke ; part of the charge that is compressed is not expelled, and expands back as the piston recedes, thus preventing the reception of a full charge of the next stroke.

A compressor with a double cylinder has the advantage over a single cylinder that in case of accident the suction and discharge stop valves may be closed on the disabled side only, and the other pump may continue to run and, in most cases, if speed is increased, the work will go on the same as before, the disconnected pump being examined or repaired at leisure.

In the case of a single cylinder double-acting compressor, should the valves on one end of the cylinder give out, if each end is provided with suction and discharge stop valves, the damaged end of the cylinder could be cut out by closing the stop valves on that end, and the valves may be taken out to be repaired while the compressor is operated single-acting.

Ammonia compression machines are operated on two systems, wet compression and dry compression, and there is considerable diversity of opinion as to the respective merits of the two systems. In practice the efficiency is much about the same, and a combination of the two systems is frequently employed.

In the wet compression system the expansion cock or valve is adjusted in such a manner that the vapour will come back to the compressor in a super-saturated condition, so that this surcharge of liquid becomes evaporated during the compression stage, absorbing the required quantity of heat and maintaining a correspondingly low temperature in the compressor cylinder. Either oil is forced into the cylinder, in order to fill the clearance spaces and to lubricate and cool the cylinder, or else a small amount of liquid ammonia is injected into the cylinder for cooling purposes. But the oil, as mentioned above, is apt to get through the whole system and to cause trouble, as well as decreasing the efficiency of the plant. The oil has to be a special mineral oil, of zero chill and 400° flash point. In the other case there is a danger of filling clearance spaces with liquid ammonia, which re-expands upon the return stroke of the piston and takes up space which is required for the reception of the inflowing gas or vapour.

In the dry compression system the expansion cock or valve is so adjusted that the whole of the liquid ammonia admitted into the expansion coil will become expanded into gas or vapour, and the latter consequently reaches the compressor cylinder in a dry condition, super-heating taking place during compression. While this plan admits of the full value of the liquid ammonia being utilized for purposes of refrigeration higher pressure becomes necessary to liquefy the ammonia, and the larger amount of heat generated calls for special arrangements for its removal. In the dry system, therefore, the outside of the cylinder is water-jacketed, and a constant stream of water is kept flowing through the jacket to carry off the heat from the cylinder and valves. The advantage of this system is that it does not introduce oil into the pipes to get into the expansion valves, and freeze or clog them up, and coat the inside of the pipes, reducing the efficiency of a plant. The disadvantage is that in large machines the cylinder walls are liable to become very hot, which causes the ammonia to dissociate.

In operating a compression plant the following are a few of the leading directions to be observed—

Carry as high suction pressure as possible. The less difference there is between the suction pressure and the condensing pressure, the more economically the plant can be run.

With a leaky piston in a double-acting compressor the gas plays back and forth past the same with great loss of power.

A reduction in the back pressure indicates that the cylinder is filled with less weight of gas, consequently the weight of gas pumped per stroke, that is, the capacity of the compressor, is reduced.

Close attention should be paid to the adjustment of the expansion valve, in order to so balance the system that the compressor shall be dry and the circulating coils wet.

The capacity of a compression machine may be increased temporarily when necessary by increasing the quantity of the condensing water, at the same time speeding up the compressor and giving the expansion valves more opening.

A compressor should not be started without ascertaining that the water is running freely over the condenser, and that every valve is open on the high pressure side, right down to the expansion valve.

A vacuum should not be pumped unnecessarily. The suction valve should be opened as soon as the engine will turn over the centres and the expansion valve opened as soon as the gauge indicates a pressure a little below the regular suction pressure. The compressor should not be stopped until the expansion valve has been shut and the suction pressure pumped down to within a few pounds of zero.

If the compressor is going to stand for an hour or more, the suction valve should be shut and the piston-rod packing tightened. But the packing must be slacked off again when re-starting the compressor.

CHAPTER V

THE AMMONIA CONDENSER AND THE REFRIGERATOR OR EVAPORATOR

In a refrigerating plant the condenser and the refrigerator (often referred to as the evaporator) have much the same relation to the compressor as the boiler has to a steam engine, that is to say, each begins and completes its work without the efficiency being dependent upon either of the other sections of the plant. As the efficiency of any steam engine is entirely dependent of the kind of boiler which supplies it with steam, and the efficiency of the boiler is not dependent upon the engine, so in a refrigerating plant no particular form of arrangement of a condenser or refrigerator is necessarily coupled with any special design of compressor. At the same time, most makers of refrigerating machines prefer and recommend certain types of compressor and refrigerator, and though, as has been stated above, these are not indispensable for successful work, provided each section of the plant to be installed is of suitable and satisfactory design and construction, it is as well to follow the maker's recommendations when practicable.

Condensers are of three kinds : " Submerged," having coils generally arranged spirally and immersed in a tank of water ; " Atmospheric," having the coils generally made of straight lengths of tube with return bends, all exposed to the air, with water trickling constantly over them ; and " Evaporative," which are similar to the atmospheric in general arrangement, but have additional devices to promote the rapid evaporation of a smaller water supply from the external surfaces.

When there is an unlimited supply of water the submerged condenser has certain advantages, one of which is that the cold water enters the tank near the exit of the condensed gas at the bottom, rising as it becomes warmer until it flows out of the tank at the top. As the gas passes into the top end of the coils, its downward flow is in the opposite direction to that of the water, and the exit of the liquefied gas is in the coldest part of the condenser—at the bottom.

Another advantage is, that in most waters the pipes keep clean longer if fully immersed. The coils of pipe usually consist of 1¼-in. to 2-in. pipe in one or more sections, preferably a number connected by manifold inlets and outlets, so that one or more of the sections may be shut off for repairs, etc. In some makes of condenser the pipe at the gas inlet end is of larger dimensions, and arranged to taper down to the outlet end, the gas being there partially liquefied and occupying less space. The pitch of the outer coil is greater than the innermost coil, so that the length of pipe in each of the several concentric coils may be kept as nearly as possible the same.

Submerged condensers are made of various types, according to the size and position of refrigerating plant. The most usual form for them consists of a thin, vertical circular tank of steel or iron. But they are also made in the form of vertical tanks, especially for marine use, in which case they are generally mounted on the same bed plate as the compressor, with grid coils instead of spiral. To make a submerged condenser thoroughly efficient the water should be kept mechanically agitated all the time it is at work, otherwise a film of warm water forms around the pipes and prevents the full transference of heat to the gradually rising body of water, which overflows at the top of the condenser tank. But the agitation should only be sufficient to keep the water moving past the surface of the coils, and should not break up the zones of temperature by setting up vertical currents, because in such a case, by making the temperature more uniform throughout, the liquid ammonia would not be cooled so much, and water would go away cooler.

Some makers supply a form of compound submerged condenser, sometimes called a "fore-cooler," in which the hot gas from the evaporator is first passed into a primary condenser, consisting of a single coil of pipe submerged in a tank; the gaseous liquid leaves this coil at the bottom of the tank and passes on to a secondary condenser, and is there delivered by a distributing head, or manifold inlet, to the tops of three coils submerged in a second tank fixed above the first one. The cooling water is admitted to the bottom of the upper or secondary condenser tank, and is taken from the top of the latter to the bottom of the lower or primary condenser tank, and finally runs off by an overflow at the top of the latter.

The atmospheric condenser consists of stacks or grids of pipes, made of continuous lengths of small pipe, 1-in. to 1½-in. diameter, or of larger pipe, 2-in. to 2½-in. built up in sections. Fig. 6 shows an open-air evaporative surface ammonia condenser in a nest of five sections made by the Haslam Engineering Company. The compressed ammonia gas passes into these condensers at the bottom, and as it rises it is cooled by the water flowing over the surface of the pipes. As the gas is cooled it liquefies and leaves the condenser by means of small pipes, which are shown at the near end of the condenser. By this arrangement the greatest possible efficiency is ensured, as the hottest gas comes in contact with the hottest water, and immediately the ammonia

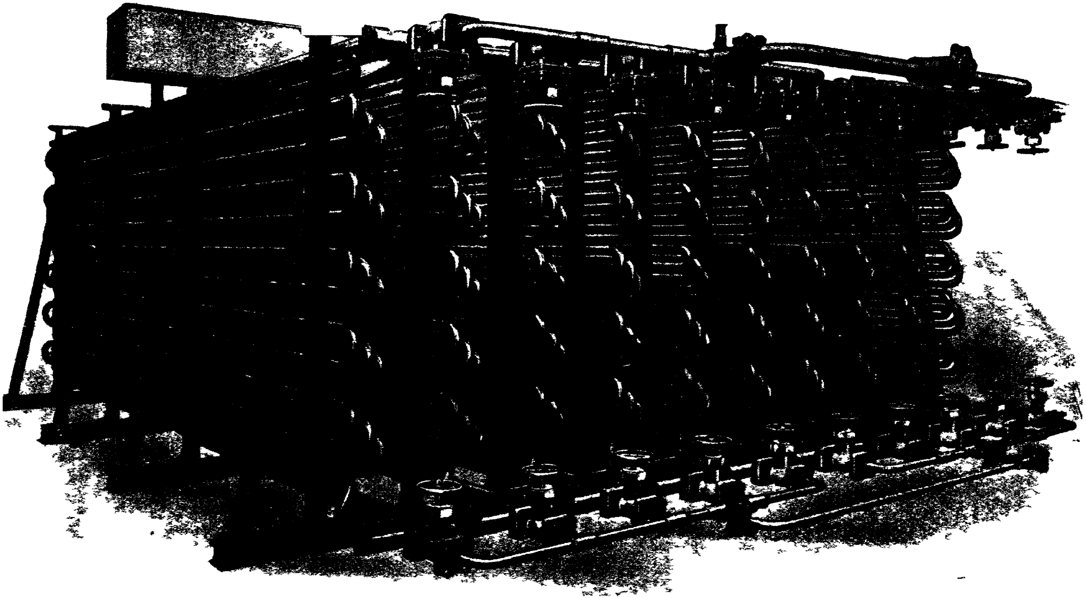

FIG. 6

is liquefied it passes away without travelling through the remainder of the condenser, as is necessary in some systems. These condensers are constructed in sections for convenient transport, and give easy access to all parts of the apparatus for repairs. Each section is provided with independent valves and cocks, so that any particular section may be shut off at any time if desired. Atmospheric condensers which are said to give excellent results are also formed of vertical sections of pipe, the compressed gas being delivered to each section at the top from a common manifold or distributing head, and the liquid discharged at the bottom into another common manifold or distributing head which is connected with the liquid receiver.

In an evaporative condenser the coils of an atmospheric condenser are covered with a light fabric which is kept wet, while an artificial current of air, propelled by a fan, is passed through them, so that a powerful evaporation is set up, and it is possible for the water to be as cool at the bottom as at the top. In such cases the gaseous and liquid medium may flow downward and still have its final cooling effected by the minimum temperature of the condensing water.

Evaporative condensers are especially suitable in warm, dry climates, and the economy or otherwise in their use depends largely upon the cost per gallon of the water and its initial temperatures, as compared with the cost of the power required to drive the fan.

Condensing water, where it is costly, is frequently used over and over again, by various arrangements, the simplest and the one in most common use being a louvred tower through which the air circulates while the water descends in a rain or spray.

The economy with which any plant may be operated depends to a large extent upon the condenser, and no harm is done by having it a little larger than is necessary. It is mistaken economy to have too small condenser capacity. Too small a condenser implies a higher head pressure, and therefore more work will be required for the compressor to accomplish the same amount of refrigeration.

Care must be taken to have the water flowing over a condenser so distributed that all the radiating surface possible will be covered, because a much higher efficiency is thus obtained.

It is desirable to use for condensing the coldest water available and to use as much of it as can be done economically, remembering that water always costs something, if it is only the cost of pumping.

The refrigerator, or evaporator, which corresponds to the boiler in a steam engine, generally consists of a series of tubes, through the metal of which the heat abstracted from the substance being cooled is conducted to the medium which flows through them, allowing the liquid refrigerant to vaporize, and by this action constituting the *refrigerating effect* of the machine. As a rule, the refrigerant vaporizes on the inside of the tubes in the refrigerator, the medium to be cooled being on the outside. The difference of temperature between the two is seldom more than 20°, and often less, so that very great care has to be taken to ensure effective circulation of the refrigerant, and proper agitation of the medium, which may be air, water or brine, in order that the greatest efficiency may be obtained.

The heat is transferred to the medium under two distinctive systems of practical refrigeration. Under the first, or brine system, as it is termed, coils of pipe are arranged as in the condenser, which are immersed in a tank of non-congealable liquid, generally a solution of ordinary salt, or chloride of calcium, from which heat is taken up by the refrigerating medium. This brine derives its heat either from vessels which are immersed in it, as when ice is to be made, or from the atmosphere which surrounds it, as when chambers are to be refrigerated. In the latter case, tubes or troughs are placed in the air of the chamber through which the cold brine flows, and this cold brine abstracts the heat from the room. An ice-making tank of ordinary type is filled with brine in which the ice cans or moulds are inserted. A centrifugal pump at the side draws the brine from under a false bottom and delivers it over the top of an end diaphragm, thus creating a perfect circulation, which can be controlled by regulating the openings in the false bottom. The expansion coil is made in one length, the only joints being the flange connections to the manifold expansion and return valve. Instead of having a centrifugal pump for circulation within the tank a force pump would be employed to circulate the brine through a series of pipe coils on the walls or ceiling of a chamber, in order to withdraw the heat from the latter and its contents.

Under the second, or direct expansion system, the gas in the refrigerator coils takes up heat by direct conduction from the air of the room to be cooled. This transference of heat may take place in the cold chamber itself, over the walls or ceiling of which the expansion pipes may be laid.

In another system of cooling chambers, frequently adopted with ammonia compression machines of the Linde type, the refrigerator cools the brine and the brine cools a series of iron plates alternately immersed in and withdrawn from it, which are arranged as revolving discs. These metallic surfaces cool the air which circulates between them, and transfer to the brine from the air the heat which it has abstracted from the goods to be refrigerated. In this latter case there is a fourfold transference of heat, and consequent loss of power, besides a great drying action, but there are compensating advantages arising from the ease with which the circulation of the air can be controlled and directed by channels wherever required. With direct expansion there is only a double transfer of heat, that is, from the goods to the air and from the air to the refrigerator ; and on these grounds it is an economical arrangement, especially as regards expenditure of power for a given amount of heat abstracted. There are certain other advantages of the brine system, as, for instance, the facility afforded for storing energy by having large tanks of cold brine in reserve which can be used in case of stoppage of the machine. Another advantage is the absence of danger by the escape of ammonia into the cold chambers.

But after all the question of deciding whether to use brine or ammonia circulation, or both combined, in any particular requirements of the use of refrigeration is one in which the advice of an expert should be taken after the whole of the requirements, as well as the conditions under which the installation is being carried out, have been laid before him.

CHAPTER VI

BRINE

BRINE, that most important constituent of any ice-making or cold storage plant, while in its elementary composition a combination of salt and water in solution, is for refrigerating purposes usually prepared with a proportion of calcium chloride, or anhydrous magnesium chloride, to produce a more rapidly operating solution.

Water at 32° F. will dissolve 51 parts of calcium chloride ($CaCl_2$) in 55·5 parts of magnesium chloride ($MgCl_2$) to 100 parts of water ; the specific gravity in either case will be, approximately, 1·36. According to Engel, a percentage solution of 17·5 of calcium chloride, or 14·3 of magnesium chloride, is sufficient to raise the boiling point of water from 212° F. to 219·2. If a unit volume of water be taken at its maximum density, 39·1° F., or 4° C., and heated to boiling point, under ordinary atmospheric pressure its volume will be 1·043, at freezing point the volume will be 1·00013, if converted into ice the volume will be 1·09 ; approximately we can say that 10 volumes of water become 11 volumes of ice, an increase of volume during freezing which has to be specially noted. One volume of water at the same temperature heated and converted into steam at atmospheric pressure will occupy 1,654 volumes.

The freezing property of the brine solution will be determined by its density, ascertained by the use of a hydrometer. Water is used as the standard for relative density. The level at which the ordinary hydrometer floats in distilled water is marked as 1,000, and marked on the Beaume and Twaddle hydrometers, often referred to, as 0.

Common salt, or sodium chloride (NaCl), is not so extensively used as calcium chloride for making brine owing to its lesser density, and the consequent difficulty in preventing freezing.

Guthrie found in 1876 that when brine made with 10 per cent. sodium chloride was cooled to 18° F., formation of ice took place, which was free from salt. This left the remaining brine of greater density, but further cooling resulted in the further formation of ice, and at −8° F. the whole was frozen. With a 25 per cent. solution, −8° can be reached without ice formation, but the whole will then freeze. The specific gravity of the brine thus made will be 1·200, recorded on the ordinary hydrometer as 1200, on the Beaume scale 24, Twaddle 40.

When calcium chloride is used alone, 20 per cent. is a usual strength for the solution ; if salt is mixed with it, 25 per cent. In either case a temperature of 8° to 18° F. is maintained, with an average of 14°. The specific gravity will be about 1·22, that is, 1220 ordinary, or 26 Beaume.

Magnesium chloride is finding increasing favour for brine making. Using a 25 per cent. solution, the freezing point will be about −22° F., and the specific gravity the same as that of calcium chloride brine. Magnesium chloride brine has for some purposes advantages over either of the other two, NaCl and $CaCl_2$. The following table given by Prof. Wemyss Anderson[1] will help to explain two of these points ; it gives the pounds of salt required per gallon of water to make saturated solutions the temperature selected—

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[1] "*Refrigeration*" : Longmans, Green & Co., London, 1908. Page 128.

Temperatures.		$MgCl_2$.	$CaCl_2$.	$NaCl$.
F.	*C.*			
65°	18·3°	5·65	7·10	3·60
55°	12·8°	5·60	6·40	3·55
0°	– 17·7°	5·30	3·60	3·20
– 10°	– 23·3°	5·20	3·50	Frozen

The brine should be made of sufficient strength to correspond to the temperature of the evaporating ammonia or other refrigerant, rather than, as is frequently, but mistakenly, the case, to the temperature of the coldest brine. The proper density of brine, either calcium or salt, is determined by the temperature to which it is necessary to be reduced, and the tables in the Appendix will be found of use in determining the proper strength for different requirements. It should be remembered, however, that a difference of from 5 to 10° F. exists between the temperature of the brine and the evaporating ammonia, and while the strength of the brine may appear ample for the temperature at which it is carried, the lower temperature of the evaporating ammonia may cause it to solidify within or upon the surface of the evaporator. The density of brine is sometimes carelessly allowed to run down, as the engineer frequently runs water into the brine tanks when he sees them getting low, and does not always think to add a little common salt to keep the density of the brine at the right point. If this is neglected it will be impossible to reduce the temperature of the brine low enough to give the desired results in the cold storage rooms. In many cases the fault is improperly laid to the ammonia compressor, the absorber, the condensers, the expansion coils not being large enough, shortage of ammonia in the system, etc., when as a matter of fact the brine is too weak to produce the desired temperature.

The strength of the brine needs close attention, for it will cause trouble and annoyance if not kept at the right density. There is considerable loss of brine from evaporation and leakage, depending upon the location of the brine tanks and the tightness of the stuffing boxes on the pump rods. Such losses as these are serious at times, and particularly where the engineer omits to test the density of the brine. If brine gets too weak it will freeze on the pipes of the expansion coil, thus forming an insulation which obstructs the transfer of heat from the brine to the ammonia within the expansion coil, and the machine will not do its full work.

The expansion coils in a brine tank should be kept covered with brine at all times, otherwise the part exposed alternately to the brine and air will oxidize, causing rapid corrosion of the pipes and leaks will soon appear in them. The exposure of the expansion coils will also reduce the efficiency of the system, as the exposed pipes will take up heat from the surrounding atmosphere instead of from the brine. The brine acts as a heat-carrying conductor between the cold storage rooms or ice cans and the expansion coils, so that in the case of a cold storage plant the service of the exposed pipes is lost entirely. In the case of an ice tank but little heat would be conducted from the cans to the exposed pipes, as air is a poor conductor of heat.

The pump section in a brine tank should be several inches above the bottom so as not to become clogged with sediment, and a removable strainer should be provided.

The first point in favour of $MgCl_2$ is that the solution is much more stable than $CaCl_2$, and the second point is that it can be used for much lower temperatures than CaCl. A good example is found in the employment of brine freezing for sinking of mining shafts, a German practice used with great success in mine sinking on the Northumbrian coast. Here, chiefly owing to the long length of vertical pipes through which the brine had to be passed and the principle of their construction, sodium brine could not be used at all, and with calcium brine there was found risk of stoppage as the separated salt collected at the bottom of the pipes. With magnesium chloride brine no such difficulties arose, a 26 to 28 per cent. solution being generally employed.

The ordinary user of refrigerating plant will generally make use of calcium chloride, which is readily obtainable and, thanks to the improved process of packing in a granular form adopted by Messrs. Brunner Mond & Co., superseding the necessity of breaking up the 600-lb. drums caked hard, easily prepared. Calcium is produced from the waste bittern of salt works, and in the Solvay process of soda manufacture, and is also a by-product in the manufacture of ammonia and ammonium chloride and lime, and in the manufacture of carbonic acid gas.

In addition to being used for brine, it has valuable properties as an absorbent of moisture, which it will absorb from anything within reach of its influence. Hence in rooms cooled direct, with brine circulating coils or expansion coils, calcium is often placed in pans on the floor, or in trays suspended from the ceiling, to intercept any moisture given off which would be detrimental to the goods in store. In order to obviate excessive moisture resulting from the condensation on the surface of cooling coils Madison Cooper arranges calcium chloride in trays on the top of the cooling coils. As the moisture is absorbed it trickles down over the coils and keeps them clean.

CHAPTER VII

INSULATION

WHATEVER system of producing artificial cold may be employed, whether for ice-making, cold storage, or transhipment of perishable produce at low temperatures, some form of insulating walls, floors and ceilings of storage chambers, ice stores, vessels' holds, or railway wagons will be a first requisite. It is essential both to keep out the hot air of the normal atmosphere or immediate surroundings, and at the same time retain as much as possible of the cold air substituted and thus save renewal.

The requisites in a good insulating material are thus summed up by Prof. Wemyss Anderson[1]. They should be—

(1) A low coefficient of conductivity at low temperatures and small temperature differences.

(2) A specific heat.

(3) High density of specific gravity.

(4) Practicable and sanitary.

(5) Non-hygroscopic, *i.e.*, damp-resisting.

Air as an insulator is not used to any extent in this country, with the exception of, in some instances, leaving small air spaces in the insulation. But in the United States a series of air spaces with the necessary lumber to enclose them generally makes up the sum total of insulation, although recent practice shows a tendency to British methods—cork, mill shaving and sawdust being packed between the lumber.

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[1] "*Refrigeration*": Longmans, Green & Co., London, 1908. Page 161.

Insulating materials, each of which will be found to have its advocate from the maker or consulting engineer's point of view, may be given as—

Silicate cotton, or as it is often termed, slag wool.
Charcoal, in flake or lump.
Cork, granulated or compressed into slabs for easier use.
Hair felt.
Pumice.
Sawdust.
Kieselguhr.

In addition to these materials timber and paper are used for casing purposes, and coke breeze, ashes, asphalt and concrete for floor formation.

Perfect insulation, an ideal condition impossible of attainment in practice, implies a condition in which there is no transfer of heat between bodies of different temperatures, and we must therefore endeavour to approach to this condition as near as possible, remembering always that imperfect insulation means loss of refrigerating effect, as well as endangering the preservation of the goods stored. Thus, while poor insulation cannot be defended from any standpoint, good insulation ensures satisfaction both in operating cost and in maintenance, even if the initial outlay is necessarily greater.

The efficiency of insulation depends upon the materials employed, the method in which they are employed, and the care with which they are applied during construction. Thus, a theoretically better insulating material, badly applied by workmen unaccustomed to the particular work, may assuredly be expected to give very inferior results to another material properly applied by men understanding their job.

Elaborate formulae may be used for determining the insulating value of a given material, or combination of materials, but the most satisfactory method is to actually determine the insulating value in a particular structure by experiment, or to rely upon sound and impartial expert advice, based upon results that have been ascertained, and values that can be looked for by experience in similar structures under similar conditions.

The following fundamental suggestions with regard to the selection of insulation may be mentioned.

No material should be used for insulation that has an odour about it that may be imparted to provisions in storage. Thus, ordinary pine is excluded from the list of available materials.

The material should be waterproof, and not liable to absorb moisture. As this is almost unattainable, the next best thing is to use a good waterproof paper to assist the insulation.

The insulating material should not have a tendency to disintegrate, rot, or settle so as to leave vacant spaces. For this reason sawdust is little used in this country, while other materials, such as silicate cotton, require an experienced workman to fill them in properly.

It is desirable that the material should be fireproof, hence silicate cotton, the only material fulfilling this requirement absolutely, has always been in great favour. But figures go to prove that materials which cannot be called fireproof, like cork and charcoal, are not found in practice to be provocative of fire by spontaneous combustion, when properly packed, and are rarely accused of spreading a fire when the latter has been caused by other circumstances.

Again, the space occupied by the insulation is a matter for consideration, especially on board a ship, where every inch saved in the thickness of insulation is soon multiplied in extra tons of cargo to be accommodated in the same hold.

For a somewhat similar reason, lightness, pumice, seldom employed for insulating land stores, was very largely employed on board ship in the early days of bringing frozen meat over from Australia, while it was easily procurable from New Zealand, where extinct volcanoes and lava abound.

Silicate cotton, or slag wool, has long held a very leading place in land stores as the insulating medium, and still holds its own, notwithstanding an increasing use of cork, in the form of granulated cork, compressed cork, or cork slabs, which is likewise a most excellent insulating material for all purposes on land or sea.

The comparative values of various insulating materials may be given as follows—

Non-conductors, one inch thick.	*Heat Units transmitted per square foot per hour.*	*Net cubic inch of solid matter in* 100.
Wool	36	4·3
Absorbent cotton	36	2·8
Live goose feathers	41	5·
Raw cotton	44	2·
Still air	43	—
Cork, granulated	45	—
Cork, solid	49	—
Charcoal, flake	50	5·3
Silicate cotton, best	50	5·7
Magnesia, calcined	52	2·3
Asbestos (in still air)	56	30·6
Hair felt	56	8·5
Magnesia covering, light	58	8·5
Magnesia covering, heavy	78	13·6
Fossil meal (Kieselguhr)	60	6·
Sawdust	76–84	16–20
Confined air	108	—

An average insulation with silicate cotton or charcoal consists of 9 ins. of the material between casings of paper each side, this in turn covered by a laying of match-boards. If, as is sometimes the case, a layer of hair felt is employed, 7 ins. of material will be found sufficient. When granulated cork is employed, 4 to 6 ins. is often considered sufficient with, of course, similar casing each side. If cork slabs are used, 4 ins. is considered a good insulation for ordinary purposes. The slabs are usually placed against match-boarding in two layers, breaking the joints in placing the second layer, and finished off with a coating of silicate plaster, enabling the rooms to be washed all over without damage to the insulation. It is usual also to apply a coat of bitumastic plaster to make the first layer of slab adhere firmly to the match-boarding, and between the two layers of slab, so that by the time the outer coat of plaster is applied the whole of the insulation becomes one homogeneous mass.

Ceilings of cold storage rooms are finished off with similar insulation to the walls, but of a less thickness, if there is a floor over also being insulated. Floors are usually composed of a thick laying of broken coke, breeze, or concrete, with a laying of asphalt or bitumen on the top to form a surface impervious to damp as well as a non-conductor of heat.

Cork slabs are made in two ways, and are described as "Conglomerated" or "Compressed." The first method, largely used in Germany and introduced from there to this country, consists in binding together waste cork, finely granulated, with pitch, or some similar material, and forming into slabs of suitable size under high pressure. Compressed cork, as manufactured by several responsible firms in England, who find an increasing demand for their excellent products, does not rely upon any binding material, as the pressure applied to the granulated cork is so great that the slab retains its form unaided. Yet, in both cases, notwithstanding the pressure applied, the air cells, which form such an important feature in cork insulation, remain uninjured if the slab is properly made.

Silicate cotton, which perhaps for the benefit of the uninitiated it is as well to mention is the slag from iron-foundries, long regarded as a waste product, is also supplied by some makers in the form of slabs of convenient size for erection, by confining it between wire netting of coarse mesh. But the usual method is still to pack it by hand carefully, between the studs placed at equal distances on the surface of the inner laying of match-boards so as to afford support for the outer laying of paper and boards.

CHAPTER VIII

OTHER SYSTEMS OF MECHANICAL REFRIGERATION

CARBONIC ANHYDRIDE MACHINES

IN its general methods of operation the carbonic anhydride system differs only from the ammonia compression system in regard to the refrigerant used. Carbonic anhydride, also known as carbon dioxide and carbonic acid gas (CO_2), is a non-poisonous gas, and a constituent of the atmosphere. It only liquefies under very high pressure, varying in amount in different climates, from 750 lbs. per sq. in. in temperate climates, with water at 50° F., to about 1,125 lbs. in the tropics, with water at 84°. This high pressure has its advantages as well as its disadvantages. The compressor is smaller in dimensions and consequently can be made more compact, while stronger built to withstand the extra pressure. An important feature is the fact that on account of the non-poisonous nature of the medium it is possible to introduce a safety valve in the system, a welcome addition to any pressure system.

Since Messrs. J. &. E. Hall, Ltd., introduced their first carbonic anhydride machine in **1889,** under the Windhausen patents, very considerable improvements have been made in this system, which is now a very formidable rival to ammonia compression, so much so, in fact, that most makers of refrigerating machinery now supply machines on both systems.

The carbonic anhydride machine is used very largely for marine installations, for cargo and passengers' provisions on merchant steamers, and also for cooling magazines on war vessels. It has also found considerable favour in dairies, hotels and restaurants because, in case of a leak, no harm would be done to perishable goods. Again, in case of a leak of gas, as high as 8 per cent. of the escaping gas could be breathed for a short time without any serious results while the presence of ½ per cent. of ammonia in the atmosphere would be decidedly dangerous. Of course, this lack of smell makes the detection of a leak difficult, but if suspected and the joints are smeared with soap suds, the leak may be detected. Should there be a serious leakage, and it remain undetected, as the gas is heavier than air it drops to the lower part of the room, so that anyone overcome by it, and falling to the ground in a faint, would run serious risk of suffocation. Owing to the careful construction of carbonic anhydride machines, which are usually tested in the works to a pressure three or four times as high as that at which they are expected to work there is very little risk of their giving way and accidents in consequence are exceedingly rare, practically unknown. In fact, a machine properly constructed for working at even 2,000 lbs. per sq. in. is safer than a machine that is improperly designed working at only 200 lbs. pressure.

In the older Hall machine, and those of similar type, the compressor gland is made gas-tight by means of cupped leathers on the compressor rod. Glycerine is forced into the space between these leathers at a pressure superior to the greatest pressure in the compressor, so that should a slight leakage take place at the gland it is a leakage of glycerine either into the compressor or out into the atmosphere and not a leakage of gas. What little leakage of glycerine takes place into the compressor is advantageous, inasmuch as it in the first place lubricates the compressor, and in the second place fills up all clearances, thereby increasing the efficiency of the compressor. In order to replace the glycerine which leaks out of the lubricator a small hand pump is fitted, a few strokes of which are required every three or four hours.

In the standard type Hall machine as now supplied a special metallic packing is used instead of cup leathers, while for some years past a special refrigerating oil has superseded glycerine for lubricating purposes.

Owing to the non-poisonous nature of the gas and its low cost, a safety valve, liable to rupture at about 1,350 lbs. pressure, is usually fitted on these machines.

When opening up a compressor to examine the piston and valves the gas has to be confined to the condenser and evaporator by stop valves fitted on both the suction and delivery sides, and any danger in starting the machine again without opening the delivery valve is thus obviated by the provision of the safety valve.

As with ammonia machines, the cycle of refrigeration requires the use of a condenser and evaporator, the flow of gas being regulated by an expansion valve between these two apparatus. As, however, carbonic anhydride machines, especially those of vertical type, are much more compactly made than ammonia machines, the condenser of the submerged type is frequently made with the evaporator coils contained in a separate, well-insulated portion of the same cylindrical vessel.

One very important advantage of these machines is that the gas has no chemical action on copper, so that, in the numerous cases where sea water only is available for condensing purposes, it can be used without fear of corrosion of the coils.

THE ABSORPTION SYSTEM

The absorption system differs from the compression system of refrigerating apparatus in its adaptability

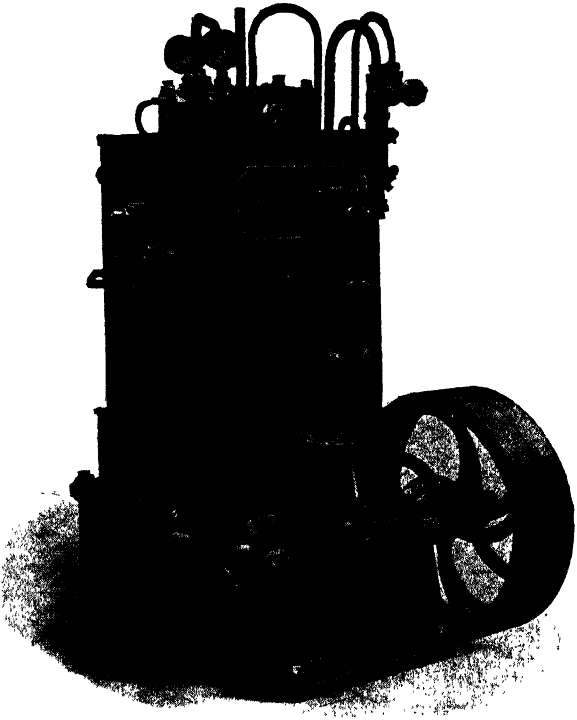


FIG. 7

STANDARD TYPE VERTICAL CO_2 COMPRESSOR BY MESSRS J. & E. HALL, LTD.

for making use of the power of absorption possessed by most liquids. It is a well-known fact that nearly all liquids have the power of absorbing different vapours of low boiling points, viz., air by water, alcohol by water, ammoniacal gas by water, etc. Water has a very great capacity for absorbing ammoniacal vapour, varying with pressure and temperature up to some 600 to 700 times the volume of the water. When brought into contact with water under pressure, the gas will be violently absorbed with the evolution of much heat. This property has been made use of in the absorption apparatus for rapidly withdrawing the ammoniacal gas from the refrigerator after it has evaporated from its liquid state, and so done its work in cooling, thus circulating the gas by chemical and physical processes rather than by mechanical means.

Absorption machines, which have been chiefly used in breweries and chemical industries, in addition to ice factories, from the nature of their construction and the space occupied, find too formidable a competitor in the compression machine amongst the users of small and moderate sized refrigerating plants in the United Kingdom, though they are still considerably used in America.

From the lesser space occupied and the greater simplicity in working, the compression machine is more readily adapted for ordinary refrigeration requirements, but in many cases an absorption plant can be more economically installed and operated where especially low temperatures are desired, as the cost of operation with the compressor increases considerably when working below zero F.

The essential parts of an ammonia absorption refrigerating system are the Generator, Evaporator, Absorber, Condenser and an Aqua Pump, as shown in the diagram

Fig. 8. The generator and absorber are charged with aqua ammonia.

In operation the generator is heated by steam in tubes, and the condenser and absorber are cooled by water. The heat of the steam drives off the ammonia gas from the generator into the condenser under sufficient pressure to cause it to liquefy. The liquid ammonia so formed passes through an expansion valve into the evaporator, where it evaporates and extracts heat from the brine or other substance which it is desired to cool. At the same time the weak liquor left behind in the generator is allowed to escape through a regulating valve into the absorber, where it is cooled by the water as mentioned above, and so brought into a condition to absorb the gas coming from the evaporator. The combination of the gas and weak liquor forms strong ammonia liquor, which is pumped back into the generator continuously for use over again.

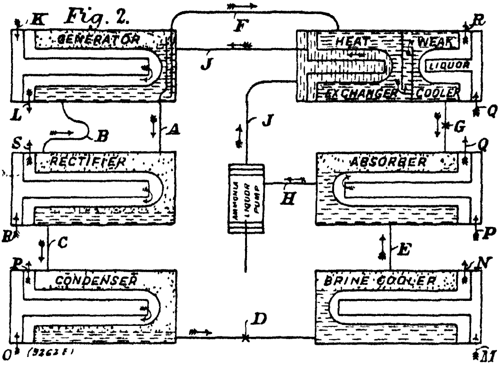


FIG. 8

DIAGRAM OF AMMONIA ABSORPTION REFRIGERATING SYSTEM

In practice two other elements are introduced into the system with the object of improving the efficiency.

The first of these is a *Rectifier* placed between the generator and condenser to act as a forecooler for the gas entering the condenser, the object being to condense any water vapour that may be mixed with the gas as it leaves the generator. The other element is known as the *Heat Exchanger*, the object being to take heat out of the weak liquor on its way from the generator to the absorber, transferring the heat so removed into the strong liquor on its way from the absorber to the generator, thus affecting an economy in the amount of steam necessary to heat the generator and in the amount of cooling water required to cool the absorber.

Machines of this type are made by Messrs. Ransomes & Rapier, Ltd., Ipswich, the general appearance of one form of their machines being shown in Fig. 9. The different elements of the system are, however, variously designed to suit the conditions in each case.

This type of absorption machine gives very satisfactory results, especially with regard to the very small amount of power required.

Messrs. Ransomes & Rapier also design machines for using steam as low as 5 lbs. sq. in. for working in conjunction with the exhaust steam of an existing engine. A combination of this type of plant and a compression system (driven by steam) can be arranged so as to give most satisfactory results. Several marine installations on this system have been supplied to British and foreign steamship companies.

SULPHUR DI-OXIDE MACHINES

Sulphur di-oxide (sulphurous acid, sulphurous anhydride, SO_2) refrigerating machines are also used to some extent in this country, and much more largely on the

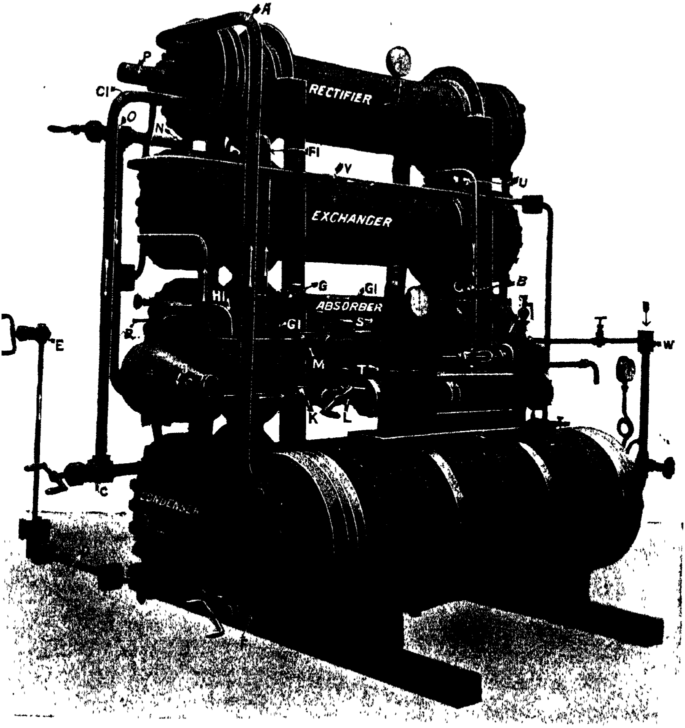


FIG. 9

ABSORPTION REFRIGERATING MACHINE BY MESSRS. RANSOMES & RAPIER, LTD.

Continent. They require, however, a much greater cylinder capacity than ammonia compressors (nearly three times as much), but the rest of the machine is approximately the same for either type. In the matter of efficiency the SO_2 machine corresponds very closely with the NH_3 machine at all temperatures.

Sulphur di-oxide in the liquid state is an excellent lubricant, and no oil is required in the compressor cylinder, and thus the oil separator of the NH_3 machine is eliminated; otherwise the construction of the machine is on the same lines as that of ammonia machines, but as the condenser pressure of SO_2 is only about a third of that of NH_3 it is the usual practice to make the piston of large diameter relative to the length of stroke.

Sulphur dioxide in the presence of air and moisture is oxidized to sulphuric acid. As long as the amount of moisture is not excessive this does no harm as strong sulphuric acid is practically non-corrosive. SO_2 machines work on a slight back pressure so that the leakage if any is outward, and there is little or no entrance of air or moisture under ordinary working conditions.

The Douglas–Conroy patent vertical belt-driven sulphur dioxide refrigerating machine is made in several small sizes. The submerged condenser is a cast-iron cylindrical tank which also forms the pedestal of the compressor cylinder and driving gear. The cylinder is jacketed and single acting, and is fixed vertically at the top of the side of the condenser with ports connecting the jacket to the water in the tank. The driving spindle passes through a sleeve low down in the body of the condenser, an arrangement which ensures the bearings being always cool. At one end are the fast and loose driving pulleys, and at the other, the disc and crank pin and connecting rod to piston. Thus the machine is well balanced and occupies very little space. The condenser contains the usual circular coil of heavy W.I. piping tested to 500 lbs. per square inch. These small machines are chiefly used in butchers' shops, dairies, and creameries, although they have been used for a great variety of purposes. The method of transforming the cooling effect varies. In meat storages the direct expansion air cooler coil with positive air circulation by means of a fan is most in favour. The air cooler may or may not stand in a tank of still, unfreezable brine to accumulate chilling effect, to be used when the compressor is not running. In dairies and creameries it is more convenient to cool with low temperature brine, so a brine tank or evaporator is used in which the brine is cooled and then circulated by a pump through milk and cream coolers, or brine drum air coolers in cold rooms for the storage of milk and other dairy produce.

The Audiffren-Singrun machine was specially designed and placed on the market to supply an inexpensive and easily operated refrigerating and ice-making machine for household use. In practice, however, it has been found that these machines can be utilized with great advantage wherever the application of cold is necessary, and in many industries where cooling is required in connection with special processes.

It will be seen from the sectional diagram that essentially the machine consists of a spherical condenser and a cylindrical evaporator joined by a hollow shaft, to the free end of which is fitted a driving pulley. In the illustration, *C* represents the condenser partly immersed in its cooling water, while *E* represents the evaporator partly immersed in the liquid to be cooled, the two connected by a hollow shaft through which passes a small pipe *H*. The usual compression cycle is adopted, a compressor of special construction being suspended from the shaft in the condenser, and weighted by means of the weight *B*, so that the condenser and evaporator rotate; the compressor remains in a vertical position. The oscillating motion is obtained by an eccentric on the shaft to which the piston is connected. The upper portion of the compressor housing is arranged in the form of a large oil container *O* into which the lubricating oil (a chemically pure mineral oil) is collected by the scoop *A* as the machine rotates. The oil then passes over the whole of the working surfaces (including the interior of the compressor) in a definite and pre-determined stream, thus ensuring perfect lubrication. One of the chief factors responsible for the success of the A.-S. machine has been the system of lubrication employed, which is so perfect that after years of working the wear in the compressor and other parts is quite inappreciable. Some of these machines have been opened up after they have been running over five years and it has been found that both the refrigerant and lubricating oil were in exactly the same condition as when the machines were originally sealed up, while the wear was so fine that it was impossible to measure it accurately. It was also found that the efficiency in each case was practically the same as when the machines were new.

The gas is sucked from the evaporator *E* through the opening by the compressor, by which it is compressed and then discharged into the condenser *C* which is rotating in the cooling water, by which its heat is extracted and in consequence it liquefies. It then passes through the pipe *H* to the evaporator, where it again vaporizes, and absorbs heat from its surroundings, which may be brine or other liquid, depending upon the form of cooling employed. The cycle continues indefinitely so long as the machine is rotated.

Before dispatch the machines are charged under a vacuum with a requisite amount of the refrigerating

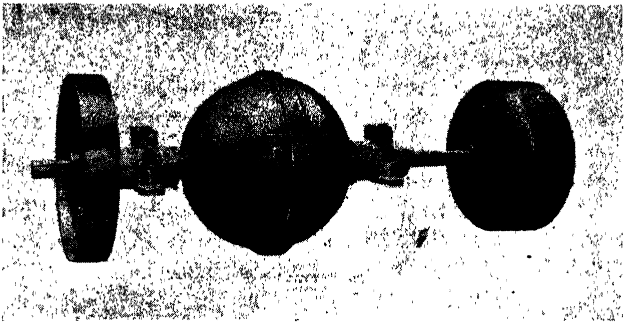


FIG. 10

AUDIFFREN-SINGRUN ROTARY COMPRESSOR

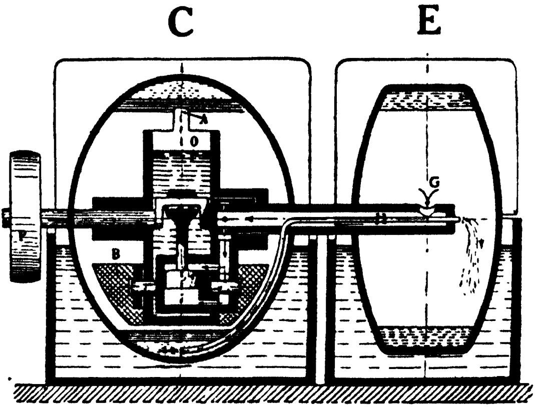


FIG. 11

DIAGRAM SHOWING CONSTRUCTION OF THE
AUDIFFREN-SINGRUN ROTARY MACHINE

medium (sulphur dioxide) and lubricating oil, after which they are hermetically sealed.

The machine rotates in two plain bearings, which are the only working parts of interest to the user; that is to say, the lubricators for these bearings have occasionally to be filled, and this negligible amount of attention is all that is required by the machine. The bearings are mounted upon the cast-iron tank through which the cooling water circulates, and in this cooling water the condenser rotates. On the other hand, the evaporator rotates in a separate tank containing water, brine, or other liquid to be cooled.

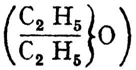
It is quite impossible for the gas to escape because the whole of the working parts are completely enclosed, while at the same time there are no valves, glands, or pipe connections through which leakage of gas could take place. This enables the machine to run for many years without recharging, an important factor which should be borne in mind particularly in districts where it is difficult to obtain the necessary chemicals.

Small quantities of ice can be obtained by allowing the condenser to rotate in a tank filled with water in which case the ice forms in a coat about ½ in. thick on the condenser itself, from which it is easily removed when the machine stops. For larger quantities of ice the tank is filled with brine in which ice cans are inserted in the ordinary way.

This machine is also suitable for cooling small cold stores, with the ordinary system of brine circulation.

Very little power is required, the smallest size machines taking about ½ H.P.

ETHER MACHINES

As mentioned in a previous chapter, ether  $\left(\left.\frac{C_2H_5}{C_2H_5}\right\}O\right)$ was one of the first gaseous mediums used of refrigeration. Many hundreds of ether machines were supplied to India and other hot countries by the original firm of H. J. West & Co., and machines of this type are still made and supplied by Messrs. Ernest West & Beynon, Ltd. An advantage in the use of ether is that it possesses the quality of working with a low pressure in the condenser, a matter of great importance in hot climates when the condensing water obtainable is naturally of a high temperature. The low condenser pressure, which does not exceed from 7 to 10 lbs. per sq. in. even in the hottest climate, permits of tight joints being easily maintained with a consequent saving of ether. The low working pressure and the great simplicity of all working parts render this type of machine very easy to operate, another important consideration where native labour is employed.

A disadvantage is the large size of compressor required, about seventeen times that of an ammonia compressor of the same capacity, resulting in increased first cost and space occupied. Another objection is the more inflammable nature of ether. Owing to its low boiling point, 34·5°, some precautions are necessary to avoid ignition when using this medium, by reason of the vapour becoming mixed with air. The formula and rules given for ammonia compressors apply also for ether, with the exception that the specific heat of the saturated vapour of ether (unlike that of ammonia, carbonic anhydride and sulphur dioxide) is positive, and therefore superheats during expansion and condenses during compression. An ether machine, therefore, needs no protection against superheating and is always operated with dry vapour. The specific heat of the liquid is 0·51.

Another very low pressure medium is methyl chloride (CH_3CL), a colourless gas, which condenses at − 20° F.

METHYL CHLORIDE MACHINES

Machines using this refrigerant have not hitherto found much favour in this country, though largely used in France, where they have been manufactured by Messrs. Douane of Paris.

The machines are mostly vertical and of small size, that is, with an ice-making capacity of 4 to 9 lbs. per hour, generally hand-driven, and up to 60 lbs. per hour when operated by a motor. Many machines of this type are employed by the French Government in hot climates. They are also used with very satisfactory results in ice factories in French East Africa. In addition to being used for refrigerating purposes, methyl chloride is also used as an anaesthetic in minor operations and for certain rheumatic complaints. It does not attack iron, white metal, or copper alloys, neither does it mix with the glycerine used as a lubricant. It has a strong pleasant smell which is not oppressive. Water absorbs about twice its volume of the chloride. The latent heat reaches a maximum value at + 50, and represents 130 calories at that temperature, and it is generally taken for practical purposes that 1 lb. of the gas will give 1 lb. of ice. It liquefies at 66 lbs. per sq. in. with condensing water at 65° F.

As the pressure used with this medium does not exceed 10 lbs. per sq. in. above that of the atmosphere, methyl chloride and ether compressors are practically identical in construction and operation.

ETHYL CHLORIDE MACHINES

Another refrigerating medium which, as the result of careful experiments, is likely to be increasingly employed, is ethyl chloride (C_2H_5Cl) which has a boiling point of 54·5° F. at atmospheric pressure ; the machine works under a vacuum and the condensing pressures are very low, about 15 lbs. (gauge pressure) as a maximum. There has been an objection to the use of ethyl chloride for low temperatures, as the liquid must be expanded under a vacuum, but this can be satisfactorily obviated by using an enclosed rotary compressor instead of a piston, a type of machine which is now placed on the market under the name of the "Clothel" refrigerating machine. A vacuum of 25 ins. represents a temperature of −20° F. which is low enough for all refrigerating purposes. The critical temperature of the compound is 365° F., and consequently no permanent gases should be involved in its use as a refrigerant. The fumes are not unpleasant, and, like methyl chloride, are not deleterious under ordinary circumstances, neither is there any effect produced on the metals previously referred to. The necessary displacement to produce an equivalent refrigerative effect is about eight times that of ammonia. It can therefore be accepted that ethyl chloride is better for refrigeration purposes than methyl chloride, and, as a rotary motion would be convenient where the compressor is driven from the axle of a railway wagon, ethyl chloride machines have been recommended by Mr. A. R. T. Woods, a well-known authority on the subject, as very suitable for railway refrigerated wagons.

THE KAPADIA PATENT SYSTEM

Dr. S. A. Kapadia has invented a system of sterilizing perishable articles of food, including the more delicate kinds of soft fruit that hitherto have resisted cold storage treatment, and he claims that under his system it is possible to keep fruit, fish, etc., in much better condition under refrigeration, at a very small increase in cost.

The chamber in which the goods are stored is charged with an atmosphere of gas which is both deoxidized and sterilized, produced in a special furnace from which it is drawn by a blower, which forces it through a cooling and drying chamber into the main storage chamber. In order to prevent the entrance of external air into the storage chamber it is made air-tight, and as the gas within is kept at a pressure slightly in excess of that of the outside atmosphere any accidental leakage must be outwards. The excess heat from the furnace may be utilized in generating steam, to drive the blower and a small refrigerating machine for drying the gases, and also for cooling them to the right temperature (45 to 55° F.), according to the substance under treatment. Once the chamber has been charged with the gas, the furnace is isolated from the rest of the apparatus, but the blower is used for circulating the gases through the chamber, and to remove any moisture that may be given off by the substances under treatment. It is claimed that under this system a smaller refrigerating plant can be used for cooling soft fruits, etc., down to about 50° F., while the whole expense of running is small, and as the gases used are practically inert there is no danger from them. Riper fruit can be more successfully cold-stored by the Kapadia process than is usually found practicable.

CHAPTER IX

ICE-MAKING

THE command of a proper supply of ice or snow for cooling water or other liquids in summer has long been regarded as one of the necessaries of life. And so ancient is the practice, that we even find allusions to it in the Proverbs of Solomon: "As the cold of snow in the time of harvest, so is a faithful messenger to them that send him; for he refresheth the soul of his masters" (Prov. xxv, 13).

The obvious method of securing a magazine of cold to meet the physical wants of summer was to collect during the winter a store of ice or of snow, and to place it where it was protected from rain, from warm air, and from the direct rays of the sun. Two methods were practised by our ancestors. The simplest method was to form the ground into a flattened cone, in order to drain off the water from any portion of the melted ice; a layer of faggots was put on this, with straw 1 ft. or more in thickness and on this ice was piled in a large conical mass, covered with straw to the thickness of 1 ft., then with faggot wood to the thickness of 2 ft. for the purpose of preserving a stratum of air above and around the ice; and, lastly, the whole was covered with 2 or 3 ft. of straw arranged as a thatch.

Most persons, however, preferred underground ice-houses, carefully drained and similarly insulated, care being taken to exclude the external air by means of an entrance passage as long as possible, provided with three or four doors, only one of which was left open at once. In filling these ice-houses the ice was usually broken with mallets or stampers to a coarse powder and well rammed down in the well or pit, keeping the upper surface concave, and adding a little water from time to time in order to fill up the interstices and assist the congelation of the whole into a solid mass. It was found that if the ice was sprinkled with salt water (1 lb. of salt to every gallon of water) the ice kept three times as long when exposed to the open air.

Snow was preserved in some places, more especially in Italy, in a similar manner to ice, by being rammed down in pits and well protected from the air at the surface. A considerable amount of snow was collected from the Apennines and stored in pits dug chiefly on the northern side of the mountains, thus furnishing the poorest of the inhabitants of Naples with a means of cooling their drinks during the heat of summer.

About 1830 there commenced a remarkable trade in natural ice between this country and the United States, which now remains only a name. A company was formed to harvest the ice on the Wenham Lake, about 18 miles from Boston, and to ship it to the East and West Indies and South America, and later on to England, where extensive ice-houses were erected in London and Liverpool and arrangements made for importing many thousands of tons of ice every year. As will be seen from our frontispiece, the ice was cut on the river in large square blocks, which were packed closely together so as to form one solid mass, the hold of the vessel having an inner lining of thick planking behind which was a thick layer of tan. On the voyage to Calcutta it was calculated that out of every 100 tons of ice shipped at Boston, at least 30 tons were wasted on the voyage, and another 10 to 12 tons on the passage up the river to Calcutta.

For many years this was the sole source of supply of imported ice. Then abundant supplies were obtained from the Norwegian lakes, with, naturally, much less cost for freight and less wastage on the shorter voyage.

The Norwegian ice import trade rapidly assumed large dimensions, reaching in 1899 the record total of 505,142 tons, valued at £317,290, while the imports from America into the United Kingdom had altogether ceased. Since 1899, owing to the erection of ice factories in the United Kingdom, Norwegian ice imports gradually declined, the total for 1913, the last complete year for which figures are available, being 235,169 tons, valued at £127,183. This trade ceased of course with the outbreak of war, and owing to the large increase in the production of artificial ice, is not likely to be resumed to any appreciable extent.

Artificial ice is made by the employment of three methods, various applications of which will be referred to later. The method most generally employed in this country is to fill specially constructed cans or moulds with water, and then place them in a tank where they are surrounded by brine, liquid ammonia, or cold air. This is known as the "Can System." The second method, known as the "Cell System," is a modification of the first, by dividing a large tank into separate permanent compartments, in which large blocks are frozen. In the "Plate System" a large tank is filled with the water to be frozen, and ice forms on each side of hollow dividing walls, through which the refrigerating coils pass. If the water to be frozen is taken direct from a town supply, an artesian well, or a neighbouring stream, it is known as "Raw Water." In some ice factories, more especially in America, the water is "Distilled" before freezing, under an impression of thereby producing purer ice. As in the case of ice formed in rivers or ponds, known as "Natural Ice," purity is usually unquestioned, from the knowledge that in freezing impurities are driven from the centre to the outside of the ice being formed, so in the manufacture of ice in this country from raw water we do not fear, like our American brethren, that we are producing anything in the least injurious for human consumption.

When the making of artificial ice first began to assume the appearance of an important and progressive industry, the chief idea was to obtain a serviceable supply of ice for cooling purposes as an addition to the supplies of American and Norwegian ice imports. Little attention was therefore paid to the quality of the produce, or to the fact that it was opaque, or cloudy in appearance, instead of transparent like the natural product. As the demand for artificial ice increased a superior article became a necessity, and consequently means were devised for producing clear, transparent, crystal ice by various makers of the plant, who patented numerous inventions of more or less efficacy, which will be mentioned in describing various systems.

In the formation of natural ice on a pond, where the water is perfectly still, opaque ice will result. If however the water is moving, as in a stream or river, or even in a gentle state of agitation, as in a large lake, clear, hard ice will result. Each molecule of water in freezing sets free the particle of air it contains ; the small bubble thus formed adheres to the surface of the newly-formed ice. If this bubble is at once built around by the growing ice, and thus becomes imprisoned, the ultimate result will be opaque ice. If however this bubble, as soon as it is formed, is washed away by the natural movement of the water during freezing, or by mechanical means, the ice will be kept clear. Opaque ice is used, when crushed, for filling the ice receptacles of trawlers, railway refrigerating wagons, etc., but it has no commercial value for table use, and it is found to melt more rapidly than hard, clear ice, natural or artificial, and is therefore apt to present an unattractive appearance on fishmongers' slabs.

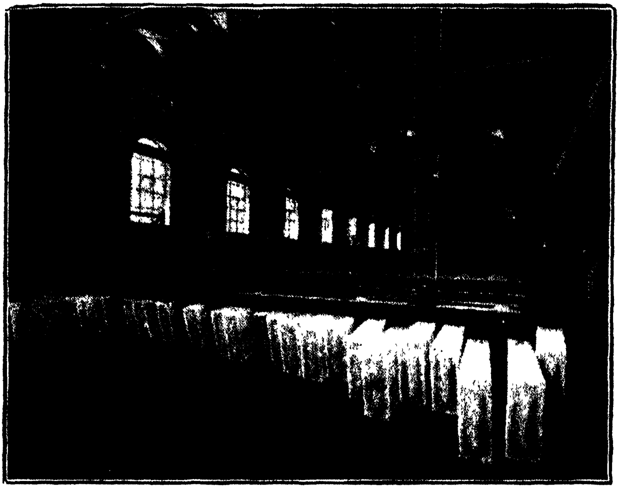


FIG. 12

ICE-MAKING PLANT BY THE LIGHTFOOT REFRIGERATION CO., LTD., SHOWING ELEVATING GEAR FOR RAISING ICE CANS FROM TANK AND DISCHARGING BLOCKS AFTER THAWING

In the Can system, tapered cans, of tinned or galvanized iron or steel (of a capacity to produce blocks of ice weighing from 56 lbs. up to 336 lbs., a usual commercial size for large ice factories), are nearly filled with cold water, and placed in a tank of cold brine, which has been cooled in separate evaporators or the evaporator coils may be placed in the tank itself. In a typical ice-making plant installed by the Lightfoot Refrigeration Co., the ammonia evaporator coils are placed under a false bottom to the tank, with openings at each end. The brine is circulated by propellers around the coils, under the false bottom, then over this false bottom, round the ice cans, returning at the other end of the tank to the coils.

The formation of clear or transparent ice can be effected by using some mechanical means of agitating the water during the process of freezing. A usual form of this agitation is by means of spirals, or endless screws, which are kept constantly revolving in the centre of the can. When the block is nearly frozen solid the agitators are withdrawn, for which purpose the agitators and the gearing by which they are driven are so arranged on the tank as to be readily removable. Under this system a slight core of opaque ice is left at last in the very centre of the block, but it is hardly noticeable.

By stopping the freezing process before the block is completely formed, the central hollow can be filled up with fruit, flowers, fish, etc., and freezing then resumed, producing a very attractive effect with the desired object frozen in the centre of a block of transparent ice.

Another method employed by the Lightfoot Company is by means of a double-necked, bottle-shaped vessel, one end of which is placed in the water to be frozen, while the other end is connected by a short length of rubber hose to a pipe in which the pressure is alternately slightly higher and slightly lower than the atmosphere. The water is drawn in and partly forced out of the bottle, thereby keeping the water in the can in a constant state of agitation. The nozzles have, of course, to be withdrawn from the ice cans before the block is finally formed, by lifting the connecting pipe bodily up, over a whole row of cans.

In an ice-making installation for the Liverpool Cold Storage & Ice Company, which may be taken as a typical example, twenty ice cans are placed in one row on two carriers. The cans are first taken to one end of the factory, and partially filled with water from a special tank, divided internally into twenty spaces, each arranged to hold sufficient water to fill a can (or mould as they are frequently termed) to the proper height. From the bottom of each division of the filling tank is a short rubber pipe connected to a metal nozzle. The whole twenty nozzles are fastened to one bar, and can be raised or lowered all together. When the large tank, or rather the series of small ones which it consists of, is being filled with water, the ends of the nozzles are kept above the water level. It is then brought over the ice cans or moulds, which have been raised out of the ice tank by means of a crane ; the moulds are filled by depressing the nozzles, and are lowered meanwhile into the ice tank ; the agitators in another row of cans are lifted, and all the rows of cans moved forward a space equal to that occupied by one ; the agitators are replaced in the cans just filled and set once more in motion. Meanwhile, at the far side of the tank, the last row of cans containing completely frozen ice blocks have been lifted by the crane, placed in a tank of warm water to loosen the ice where it touches the sides and end of the mould, raised out of this " thawing off " tank, placed on what is termed the "rocking-table," where they are tipped half over and the blocks of ice slide out of the moulds on to a table from which they are eventually moved along to a storing chamber most conveniently arranged on a floor below, so that the blocks slide along an inclined plane to an opening at the top of the chamber. In the particular installation described, the blocks weigh 1¼ cwts., the size being 7 in. × 13 in. × 48 ins., the total capacity of the tank of forty-eight rows of cans, twenty in a row, being 60 tons. As 48 hours are required to fill, freeze and thaw-off a can, the daily output of a tank of this size is 24 tons.

In this can system of freezing it may be assumed that a 56 lb. block of ice will take from 30 to 36 hours to freeze hard, if its thickness does not exceed 4 ins., other sizes of blocks increasing in the time taken to freeze in proportion to the thickness and width of each.

The Cell system of ice-making most generally met with in this country is known as the Siddeley system, and is supplied by the Liverpool Refrigeration Company, successors to the old firm of Siddeley. In this case a tank is fitted up with hollow divisions in such a manner as to provide a number of cells, or spaces, in which ice blocks are formed of a larger size than those made in cans, a weight of 5 cwts. being a usual one. While cold brine is being circulated through the hollow dividing walls, a paddle or plunger is worked up and down, keeping the water in constant motion and forcing it up through holes in a false bottom into the cells, as long as ice is being formed. When the block is practically completely frozen, the water is drained away from the false bottom, warm brine circulated instead of cold, and the ice block thus loosened in each cell. It is usual under the system to freeze in the block a piece of rope to form a handle by which the block can be lifted out of the cell. In the case of blocks of this size, three days are practically required for the complete process.

In the Plate system, which, although very largely employed in the United States and on the Continent, has never found much favour in this country, we have the original plan of making artificial ice which was invented by Twining and Harrison in 1850 to 1856.

Hollow or cellular plates or walls of sheet or cast iron are placed in a specially constructed and properly insulated tank, which contains the water to be frozen, while cold brine is circulated through the hollow dividing walls. The brine is either cooled in a brine-cooler or refrigerator by evaporating coils connected to a compressor, or, in an ammonia absorption plant, to the absorber ; or the refrigerating coils may be placed within the hollow walls themselves. Layers of ice soon begin to form on each side of the hollow wall, gradually increasing until a block of ice is produced of large size, weighing, that is, several tons each.

Taking as an average size of tank one 16 ft. long, 8 ft. 6 ins. wide, and 7 ft. deep, with three hollow walls 30 ins. apart, six blocks of ice, beautifully clear providing the water has been kept well agitated during freezing, will be produced, each 15 ft. × 6 ft. 6 ins. × 12 ins., weighing each about 5 tons. In thawing off, warm brine is circulated through the hollow walls until the block is sufficiently loosened to permit of its being drawn up out of the tank. Such ice, however, requires from nine to twelve days to freeze, and this is why it has not found favour in British ice factories. In America, where the demand for ice for table use is, of course, a most important branch of the industry, it is held that the longer time taken in freezing is amply justified by the much clearer ice produced.

These immense blocks of ice of course require cutting, and this is done by means of saws, working horizontally when the block has been lifted out of the tank and placed on a table for the purpose, vertically in some factories where the whole block is cut into pieces of ½ ton or so while in its vertical position on the plate.

In the case of domestic requirements for small quantities of ice the Audiffren-Singrun rotary machine, described in another chapter, can be recommended, as a small quantity of quite good ice can be produced in a very short time. In this case, the evaporator forms part of the refrigerating machine, being a circular vessel rotating at the opposite end to the condenser, on the same hollow shaft which runs through from the driving pulley. As the evaporator revolves at high speed in a vessel containing the water to be frozen, a film of ice is rapidly formed upon its surface, which can be readily detached as soon as it is considered of sufficient thickness.

A method of making plate ice, adopted by the Pulsometer Engineering Company, is by placing coils for the direct expansion of ammonia in the water to be frozen, where they are covered by one or more plates immersed in the water. The liquid ammonia is allowed to expand in the freezing coils and ice is formed on the surface of the plates. When ice of sufficient thickness and hardness is completely formed, hot gas from the condenser is allowed to flow through the coils, and the ice blocks are thawed off. Ice made by this system is usually 8 ins. thick, 8 ft. long and 6 ft. wide, but can be made up to quite double this thickness if desired. It is claimed by the makers that ice produced under this system is more nearly equal to the best Norway ice than that made by any other method, and more economically produced owing to there being only one transfer of heat.

Ice of excellent quality is made on the expansion system by the "Empire" Direct Expansion Ice Plant Co., of Liverpool, whose system embodies the patents taken out by Mr. H. J. Laurenson and Mr. W. T. Thorne. The makers claim that while making ice by direct expansion is already a superior and more economical system than by brine circulation, their own system effects still further economies in the cost of installing, in the time required to produce ice of high transparency, and in the general expenses of working. The " Empire " plant, as described by its makers, comprises a main containing tank made in sections of a standard size to admit of ease and expedition when first erected, or in the event of an enlargement or a removal. This main tank is provided with an inner tank, which in turn is subdivided into compartments of a convenient size in which ice may be formed. Ammonia is expanded in the hollow walls which form these compartments. The blocks of ice as formed are rectangular in shape, and are readily lifted from the tank after thawing off, effected by surrounding the ice cells with warm water, which also flows through a space between the bottoms of the

FIG. 13

" EMPIRE " DIRECT EXPANSION ICE PLANT

cells and the bottom of the main tank, so that the block of ice in each cell is equally thawed all round. Transparency in the ice produced is ensured by a simple arrangement of taking air directly from the atmosphere and conducting it into the space between the bottom of the freezing cells and the bottom of the tank, so that the water in this lower cavity is kept in a disturbed state and in turn agitates the water in each of the cells, apertures in the bottom of each cell allowing of this agitation. The warm water, after being used for thawing off, and thereby lowered in temperature by some 30°, is passed on to the next tank to be frozen in turn, thus effecting a further economy in working. The hollow dividing walls through which the ammonia gas passes during its expansion are made of mild steel, and so constructed that any leakage is practically impossible.

A phase of the working of the "Empire" system which claims special notice is that, owing to the very low temperature of the hollow walls in which the expansion of the ammonia is in progress, or has taken place, and of the ice in the freezing compartments, the freezing effect will continue in the latter, upon the water which has not been wholly congealed, after the machine has been stopped. In the brine system it will be found that a stoppage in the refrigerating machine is followed by a marked rise in the temperature of the brine.

The time occupied in making blocks of ice 12 ins. thick by the "Empire" system is from 22 to 24 hours, so that a great saving in time of manufacture is effected, as well as in space occupied by the plant, which does not need the pumps, pipes, coolers and tanks used in other systems.

A new system of making ice by direct expansion is known as the "Pluperfect" system, there being no cans, cells, brine nor pumps required. This is a considerable saving in space, power and expanse, and the system can be adapted to any existing plant, as it is being increasingly employed with very satisfactory results.

The main feature is the fixing in a large tank, to contain the water to be frozen, of a large number of vertical evaporators in parallel rows. These evaporators are composed of " D " sectional tubes, the tubes being bent in the form of a " U," with the flat side outwards. They are then fixed together in pairs by spot welding, and the cross joints at the top welded, and afterwards another " U " bend is formed by fixing a stamped steel cap over the two " D " pipes. The welded pipes are then assembled in numbers as may be required, according to the size of the blocks of ice required, and the width of the various tanks, to suit local conditions. The evaporators are placed in the tank at about 15 in. centres, thus allowing ice blocks to be made any size, say from 6 in. to 14 in. thick. When the tank is filled with water these vertical pipes are submerged.

The refrigerant is admitted by valves on a regular plan of rotation to different sets of evaporators, and the ice forms round the upright pipes as round crystaline columns of clear ice, the pipe forming the central core. Clear ice is formed and provision made for thawing off the blocks by the admission to the pipes of liquid ammonia, and to ensure the release of the ice from the bottom surfaces, thawing off pipes are interposed between the former plates and the bottom of the ice tanks. Through these pipes steam or hot water is allowed to flow. The time required to release the ice from the tubes and the bottom is only a few minutes.

A system of ice-making by means of a vacuum instead of a refrigerant has been patented in America by Mr.

Patten of Baltimore, but has not been proved a commercial success, as the ice formed is opaque and brittle, though otherwise of good lasting qualities. Under this system a fine jet of water, or series of jets, is caused to rotate and at the same time move vertically up and down under a vacuum in a closed circular vessel called the " ice-former." A hollow cylinder of opaque white ice is formed, about 6 ft. in external diameter and 4 ft. internal, from which blocks of commercial shape and size can be cut.

The cost of ice-making, before inflated war prices for labour and material were experienced, while varying of course with the size of the plant and economical working ranged from 2s. 6d. per ton of ice to 4s. 6d. Coal is, of course, a chief consideration when employed to furnish power. As much as 20 tons of ice has been frequently made with 1 ton of coal, but a usual average is to estimate 10 lbs. of ice per 1 lb. of coal. Probably, under existing conditions, at least 300 per cent. must be added to pre-war cost of production. But as cost of natural ice has gone up in proportion, and freights are exceedingly high, the cost of a ton of artificial ice will still be found considerably less in first cost, in addition to the many advantages of producing an article as and when required in the vicinity of its chief outlet for distribution.

CHAPTER X

THE COLD STORE

It is not proposed in the present work to deal with the design or construction of huge cold stores, erected under the supervision of a consulting engineer and operated by an experienced staff. The object of this handbook is to provide a general knowledge of the whole subject, to enable an ordinary user of refrigeration to know sufficient of rudimentary principles to avoid mistakes, and the aim has been to keep as far as possible from introducing unnecessary statistics, tables or calculations.

The internal arrangement of a small cold store is, as regards its special requirements, exactly similar to a large one. It needs to be economically planned, suitably constructed, thoroughly insulated and, carefully looked after.

As with a large cold store, square construction is desirable, as this best lends itself to insulating economically. Brick, stone or concrete is preferable naturally to wood for the walls, as the former are worse conductors of heat and therefore require less thickness of insulation. Position with regard to other rooms in use should be taken into consideration as the power employed to drive the refrigerating machine, if it be steam or gas, may be available for some other purposes in an adjoining chamber. Again, the present position of a steam or gas engine may be an important factor in deciding upon the position of the cold chamber to be arranged for. In the case of electric power, now so universally adopted for small plants, this question will not arise, the motor usually forming part of the plant, and the current being easily brought thereto from any convenient source of supply.

The next point to consider will be the entrance to the cold room. The ideal entrance, of course, is from the top. Cold air being heavier than warm air has a tendency to sink to the lowest level, so that it is customary in modern stores to arrange for the delivery of goods to and from the store being made from the uppermost storey. With only one or two small rooms this is of course impracticable, but it is an advantage to have them open into a well-insulated corridor or lobby, or in the case of a single chamber, into an ante-room, so that the warm outside air cannot penetrate directly into the cold chamber. The great object to be aimed at is to have the cold chamber so economically constructed, cooled and attended to that it shall preserve its low temperature as much as possible, so that mechanical refrigeration need not be employed during the whole of the 24 hours. Leaving for a moment the question of producing cold by the use of ice or calcium chloride brine, as in the Cooper Gravity System mentioned elsewhere, we take it that the room having been allocated or constructed specially, and properly insulated, one or other of the small refrigerating machines on the market has been decided upon for purchase. The next question to be dealt with will be the best means of applying the artificial cold that this produces to the cold storage chamber. Three ways are available: circulation of cold brine through pipes along the walls of the chamber or arranged along the ceiling; circulation of cold air by blowing cold air over the brine pipes in another room or over expansion pipes outside the cold room; and by means of direct expansion coils in the cold room itself. The advantages resulting from either of these three methods depend to a large extent on the kinds of goods placed in cold store. Many stores, large and small, are quite satisfactorily cooled by the brine circulation system, though advocates of the other systems will claim that there is too much moisture and not sufficient air circulation. Nearly all stored goods give off more or less heavy gases, and where pipes alone are used for cooling, however good the circulation of the air by means of suitable arrangement of pipes may be, these gases remain and often collect at the bottom of the chamber, so that goods stored on the floor, or parts of other goods which touch the floor, will be apt to get into bad or at any rate inferior condition.

Prof. Anderson recommends a combination of brine circulation and air cooling as giving excellent results, though not often carried out. The fan and the air ducts assure an efficient circulation of the air, while the brine in the pipes, in addition to performing the ordinary cooling, acts as a " reserve of cold," or in other words, helps to keep a uniform temperature by providing a large bulk of very cold material, which must be " heated " before the room can experience a serious rise. This question of uniform temperatures is the really essential thing for good storage and all recent advances in methods of construction, management and storage, which have been adopted on land or sea have had that end in view. Fig. 14 shows an excellent method adopted by the Lightfoot Refrigeration Company for cooling small chambers. An air cooler is placed in the cold room at one side, a fan being provided to produce a circulation of air. The air cooler usually consists of a galvanized tank filled with brine in which the ammonia or carbonic acid refrigerator coils are immersed. The large store of cold brine keeps down the temperature of the room for a considerable time after the machine has stopped ; in fact, the temperature in the morning is often lower than it was when the machine was stopped the evening before.

The Haslam Company have made a special feature, especially in the large chambers devoted to cold storage of mixed produce at the docks, of apparatus for cooling air to be circulated through cold storage rooms.

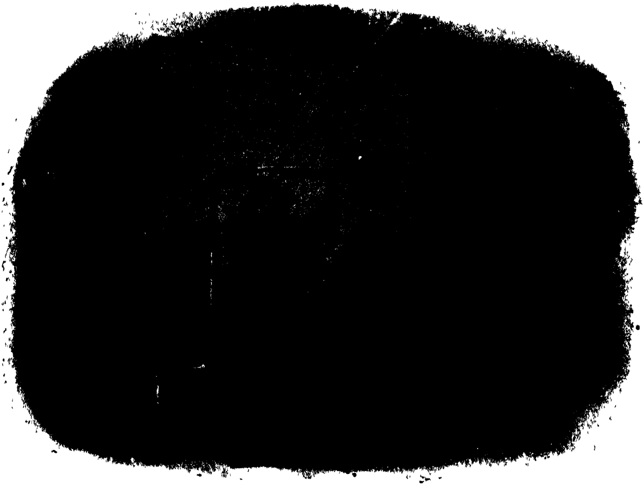


FIG 14

LIGHTFOOT SYSTEM FOR COOLING SMALL CHAMBERS

The "Haslam" Air Cooler consists of galvanized corrugated steel plates from 5 ft. to 8 ft. in length placed vertically about 1 in. apart and arranged in nests, the plates being secured by through bolts and kept apart by distance pieces or ferrules threaded on the bolts. The nests of plates are placed above a steel brine tank, and the ammonia cooling coils are either arranged

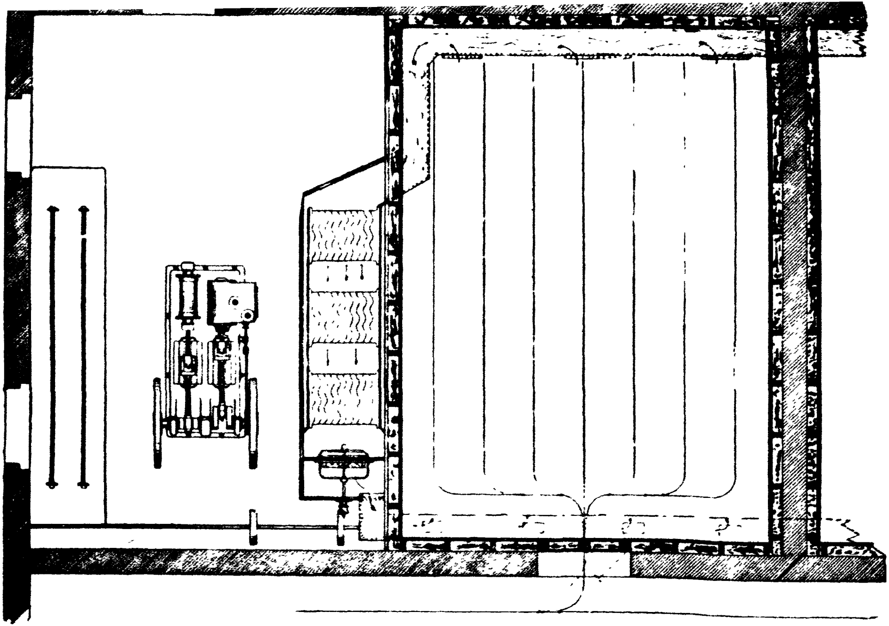


Fig. 15

HASLAM AIR COOLER FOR COLD STORAGE CHAMBERS in this tank or are placed on each side of the nests of plates, in which case the surface of the pipes is available for air-cooling. Brine distributing trays are placed on the top of the nests of plates. These trays have slotted bottoms, the slots being arranged immediately over each plate. The distribution of brine is further effected by slotted pipes placed above these trays communicating with a central tank, but this tank is supplied with brine from the lower tank and circulated by a centrifugal pump, also light cast iron distance pieces are laid on the belts securing the plates together at the top, which ensures the brine falling on to the plates being spread over their surface. These distance pieces can be easily removed for cleaning. A fan is provided for circulating air through the rooms, and if the cooling pipes are placed in the tank, a propeller is often included for circulating the brine over the coils.

Cooling by direct expansion of liquid ammonia, the only refrigerant used to any extent for this process, is by many engineers considered to be a more economical and rapid system of cooling than by brine circulation ; the apparatus required is simpler, and consequently the first cost on installation is reduced. The liquid ammonia at low pressure, say 30 lbs. absolute, is passed direct into coils placed in the chambers, and the heat necessary for its evaporation is taken from the air in the rooms. All the regulating valves for the various sections can be placed in or near the main engine-room, and the return pipes serve as indicators of the work performed by virtue of the amount of frost they carry.

Against this economy in cooling power, and also in space and cost of installing, must be placed certain disadvantages. These include risk of fire, and damage to goods stored in case of leakage of gas from the cooling pipes, though this can be guarded against if a high-class firm is entrusted with the installation, who will see that every possible care is used in selecting the material, as well as in construction. But there is also the impossibility of shutting down the refrigerating machine even for a few minutes without the cooling pipes commencing to drip, while there is similarly no reserve of cold in case of temporary breakdown.

Another system of cooling a cold store is that patented by Madison Cooper in the U.S.A., and much recommended in that country and Canada as a cheap and economical system of producing artificial cold. In this system, usually known as the Cooper Gravity System, the air is washed, cooled and dried without the use of a refrigerating machine, and it is claimed to be especially serviceable for the storage of eggs and dairy produce. The apparatus, of which Fig. 16 is a diagrammatical view, includes an air-washing tank in which the air is caused to flow upwards against a rain of water from a perforated diaphragm above. This operation cools the air to the temperature of the water, say 55° or 60° F., and also takes out a large amount of the impurities of various kinds which it contains. From this washing tank the air is passed on in a comparatively pure and cooled state to be still further reduced in temperature by being passed over brine coils in a cooling tank, which it leaves at several degrees lower temperature than that of the storage chamber. This second cooling removes the greater portion of the moisture which holds in suspension the few impurities which may have passed the washing tank, the moisture being deposited on the frozen surfaces within the cooler. The tank in the upper part of the building and one in the storage chamber really form one continuous series of coils; that in the upper part is surrounded by crushed ice and salt, and the cooled chloride of calcium brine as it falls, being heavier than the warmer and lighter brine below, forces the latter upwards again, thus creating an automatic circulation, it being necessary only to fill the tank with ice and salt once a day. Cooper claims a temperature of 6° F. by his gravity brine system, and says temperatures of 12 to 15° are easy to maintain. The system may be said to work well down to 12° F, but below that point melting of the salt is too slow to be practically operative. At, say, 30°, the action is rapid, and no trouble is experienced in keeping a sixteen-pipe coil free from frost.

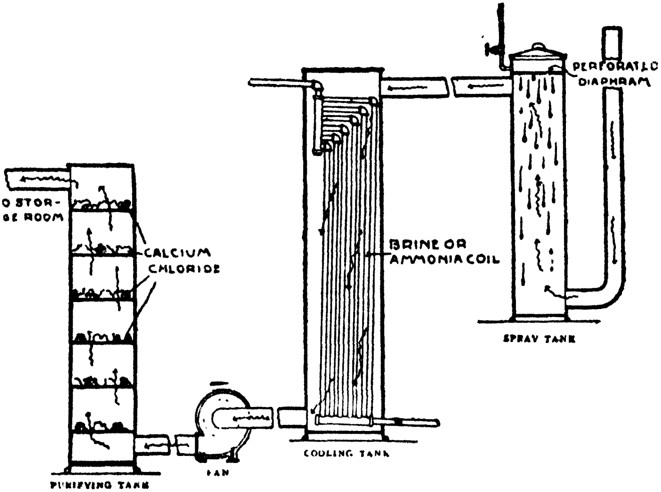


FIG. 16

COOPER'S CALCIUM CHLORIDE SYSTEM OF AIR-COOLING

It will be seen by the illustration that the cooled air passes over trays of calcium chloride in the storage chamber, for drying, a system much recommended by Madison Cooper for `use in all cooling systems where any superfluous moisture is to be apprehended which may prove detrimental to the goods stored. Further details of this method will be found in the chapter on brine preparation and employment.

While great care may have been taken with the insulation of a cold room, and the floor and walls carefully constructed to combine cleanliness with freedom from damp, a weak point in some rooms is the door. This is without doubt the most important point of the whole construction, as with an ill-fitting door, insufficiently insulated, all the effects of the most capable system of refrigeration will be frustrated. Starting with the general principle that as few doors and windows as possible should be used in any cold store, windows, if absolutely required, being at least trebly glazed and perfectly insulated, the doors must be of a special cold storage type, carefully constructed, accurately hung and adjusted, well insulated, and the fittings so arranged that the doors, while perfectly easy to open from either side, will lock tight when the door is closed. A room that will be used for the storage of perishable produce for any length of time, as distinct from one used by the butcher or provision dealer for merely temporary storage, should always open into an ante-room, as the entrance of warm, moist air into the storage room, inseparable from opening the door, has a disastrous effect upon the goods. In many cases it will be found an advantage to have small hatches, or plug-doors, in the main doors, though which goods can be passed in or out without the atmosphere of the cold room being so largely affected as it is by the opening of the main door. A well-designed door, largely used in British cold stores, is that shown in Fig. 17, made by John

Straiton, of Liverpool, with Taylor's patent fittings. Messrs. Wallington Jones & Co. also specialize in doors and fittings of excellent design and reliability. A door should be insulated fully as thickly, if not more so, as the wall of the chamber, a recommended insulation being 1-in. tongued and grooved match-boarding, two layers of insulating paper well lapped, another 1-in. match-boarding, 12-in. space filled with silicate cotton, 1-in. match-boarding, two layers of paper, and 1-in. match-boarding to complete. But the most careful construction, adjustment and insulation will be useless if the door is not made of the best well-seasoned timber; otherwise it is bound to give trouble on account of the variations in temperature to which it is so constantly subjected, and the absorption of moisture from the air. An extra first cost in the doors of a cold store will be amply repaid in freedom from loss by deterioration in goods due to improperly constructed and ill-fitting doors.

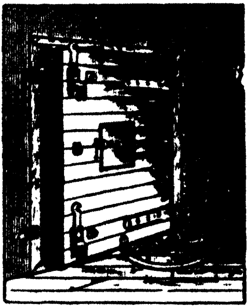


FIG. 17

COLD ROOM DOOR, WITH TAYLOR'S PATENT FITTINGS, BY MESSRS. JOHN STRAITON & SONS

In large cold stores, arrangements are usually made for the overhead run-way to be continued through the top of the door-frame, while the cill is removable to admit of the passage in and out of trucks, but of course these are only possible where entrance is from an anteroom or well-arranged and insulated corridor. S. P. Stevenson, of Chester, Pa., whose cold store doors and fittings are very largely used in the United States, has specialized in this feature.

CHAPTER XI

APPLICATIONS OF MECHANICAL REFRIGERATION

It will be readily conceded that the most important application of mechanical refrigeration has been the development of the carriage of the produce of far-distant countries to assist the ever-increasing demand for food supplies, in Europe generally, and in Great Britain in particular, enabling the meat, dairy produce and fruit to be imported under the very best conditions, and stabilizing prices while insuring plenty.

Next to this application we must place the manufacture of ice as another successful means of assisting Nature in the production and supply of an article of ever-increasing consumption and consequent demand.

But apart from the preservation of food products, and the manufacture of ice, mechanical refrigeration, the artificial production of cold, has been proved year by year of ever-increasing value in the manufacture and preparation of so many articles of commerce that whereas at one time one might have given a short list of the various industries in which refrigeration was employed, at the present time it would almost be easier to give a list of the industries in which it does not, to some extent, play a direct or indirect part.

Dealing first of all with articles of food, every wholesale or retail seller of groceries, provisions, dairy produce, meat, poultry and game is more and more dependent on cold storage for preserving his supplies of perishable produce, either with his own plant or through the large public cold stores.

The modern *Dairy* would be lost without its refrigerating plant. This enables the milk to be reduced in temperature immediately after being taken from the cow ; the cream to be adjusted to the proper temperature for churning ; the butter thus produced under the most favourable conditions, can be held after churning in prime condition as long as required in the cold room adjoining the dairy. Thus prices of milk and butter can be better regulated by the ability of the producer to hold his goods on the spot in their original good condition until required for sale or use.

Cheese. Refrigeration is to some extent made use of in Great Britain in the manufacture of cheese, in regulation of temperatures, and more largely in the stores where the cheese is ripened afterwards. In Canada and the United States no cheese factory would be considered complete now without its refrigerating plant, for both purposes, while the shipments of cheese from North America and Australasia are all now made in refrigerated holds, to the very great advantage of both importers and consumers.

Fish, for so many years past depending on ice for its preservation on the voyages of the fishing vessels, of thereby increasingly longer distances and time occupied away from port, is now frozen hard, under various methods, at the port of arrival in some distant land, such as Newfoundland or British Columbia, and shipped to this country in perfect condition, especially salmon and halibut, enabling a most desirable form of cheap food to be more largely made use of. And practically every fishmonger has his ice-cooled refrigerator to preserve his supplies in good condition, while an increasing number year by year are substituting the more economical refrigerating plant for the antiquated ice-box, with its greater trouble and less efficiency.

Bacon, at one time only shipped from America and Canada salted, is now brought over green, in refrigerated holds, for curing to taste over here to suit the most particular palate, especially when aided by the sterilizing process patented by Mr. Linley which has proved as successful for bacon as it has with chilled beef. The need of refrigerated holds for shipping this important article of our food supply was never more exemplified than in the terrible waste of bacon imported from America during the War, under contracts too hastily entered into with profiteers, when over-salting was foolishly resorted to when refrigerated vessels were not available, and the opportunity for selling salt at 1s. 4d. per lb. was eagerly seized !

Fruit is now brought from South Africa as well as Australia and California of the most delicate kinds, in excellent condition, enabling these distant countries to contribute of their plenty, and often in out-of-season periods, to those less favoured. Again, in times of glut, a ready means is afforded to the salesman, the importer, or the jam manufacturer, of holding over fruit of all kinds in good condition.

Beer. Refrigeration, long employed in the German and Danish breweries, in the brewing and for the storing of lager beers, now forms an essential part of the plant of every modern brewery, chiefly for the more rapid and adequate cooling of the wort, but also to a very large extent for holding the storage cellars at proper temperatures.

Cold storage is also extensively employed, both by brewers and merchants, for preserving *Hops* until they are wanted for consumption. When held at a low temperature hops retain their choicest aroma, instead of, as previously, deteriorating greatly after a few months' storage under ordinary warehouse conditions.

Wine, especially in the celebrated champagne districts of France, finds extensive employment for artificial cooling, not only in the storage cellars during the long periods of maturing for market, but in connection with the periodical removal of corks during the years that elapse between the squeezing out of the juice of the grapes and the placing of the matured product on the consumers' tables. In the treatment of champagne, the final fermentation takes place while the bottles are tightly corked and inverted. The yeast collects on the cork. When ripe, the cork is quickly withdrawn and replaced, the yeast being allowed to flow meanwhile. Even with the greatest care loss is unavoidable, but with the introduction of refrigeration the heads of the bottles are placed in a solution of glycerine of about 0° F., when the yeast freezes in about ten minutes, and can be withdrawn with the cork without loss and without requiring any particular skill.

In *Sugar* refineries, refrigeration is employed to regain the sugar from the molasses residues, and for the concentration of saccharine juices and solutions by freezing or congealing the water particles, which are then removed, leaving the residuum of a greater strength.

Margarine factories are large users of mechanical refrigeration, not only for cooling the milk to a suitable temperature for churning, but in solidifying the emulsion resulting, for which operation cold is applied in various ways. This emulsion is either plunged in its containing vessel into water at a low temperature, or cooled by cold air circulated over and around it, or it is poured in thin streams over cooling coils through which the brine or cold air is circulating.

Lard, or the substance which goes by that name in the present day, is equally dependent on refrigeration for the solidifying stage of its manufacture, and a very large number of refrigerating machines are supplied to the lard manufacturers.

Chocolate manufacturers have become almost universal users of refrigerating machinery. The first installation of an artificial cooling plant was at Messrs. Fry's factory in 1882, when a Lightfoot double-expansion horizontal cold-air machine was purchased, which it was soon found enabled processes which had previously to be suspended during the hot weather to be carried on equally well throughout the year. A great saving in chocolate making is effected by the rapid solidification thus rendered possible, while considerable waste is also avoided. The chocolate also leaves the moulds readily and quite intact, and in consequence fewer moulds are needed to do the same amount of work.

One form of chocolate cooler largely employed is made by Messrs. Arthur G. Enock & Co., in the form of a rotary frame of six sides from which trays of chocolate are slung, which slowly rotate through a cooling drum, by which it is claimed that each tray gets the same amount of cooling as it makes the complete circuit of the cooler. Messrs. Menier & Co., the celebrated French chocolate manufacturers, make use of an endless travelling band, by means of which the trays of chocolate are slowly carried along through a refrigerated chamber on a method similar to that in which biscuits are passed through an oven in modern systems of baking.

Stearine factories make use of refrigeration to crystallize the expressed fatty acids, and to recover the dissolved stearine from the olein. A similar process is needed with respect to *Oleo-margarine, Edible Fats, Tallow* and *Tallow Oil.*

Glycerine manufacturers employ artificial cold to separate liquid glycerine from certain fatty bodies in order to obtain a lower melting point. The clarification of all these fatty substances is largely assisted by the low temperature now so easily produced and retained, in the making of candles and soap from them, and the production of varnish from linseed oil.

Oil refiners have for many years past found artificial refrigeration indispensable for the purpose of separating the paraffin wax from the oil and refining the oil at the same time. As mentioned in Chapter I, one of the first refrigerating machines commercially employed in this country was installed at a Scotch oil works.

Furs have been for many years now kept in cold storage and it is a profitable business for furriers to receive the furs of private customers at the close of the season. These goods, along with the firm's own stock and carpets, woollen garments and silks, are held at a temperature of 25° to 35° F. A temperature below 30° F. prevents evaporation and maintains the lustre of the silk, while with furs it is like putting them back into their original element, and the natural gloss is preserved as when on the animal's back. Another advantage is that absolute security is insured from the destructive ravages of moth.

In the *Silk* industry the eggs of the silkworm are kept in cold storage, in order that their hatching-out shall coincide with the maturing of the leaves of the mulberry trees on which they feed.

Flower growers employ refrigeration to retard the growth of flowers and bulbs, or to regulate blossoming, as well as for storing and shipping.

Chemical Works are extensive users of artificial refrigeration as so many of their operations depend largely on differences in temperature especially involving crystallization processes, which can be greatly assisted by refrigeration. Glycerine is a well-known instance of this kind, and another remarkable example is chloroform. This substance, when considered pure, was nevertheless of a very unstable character. But Pictet proved that an absolutely pure chloroform could be obtained if it was crystallized at a temperature of about −90°.

In the manufacture of *Dynamite* it is kept at a low temperature during the process of nitrating.

Other large users of refrigerating machines are *Ice-cream* makers, especially, of course, in America ; *Photographic* material makers, in the preparation of gelatine plates ; *Paint* factories ; *Glue* factories ; *Indiarubber* works ; *Glass* works and *Lens* factories ; *Dye* works ; *Blast* furnaces for the manufacture of steel, and *Distilleries*.

Even in the *Timber* trade, low temperatures are found beneficial in hastening the process of seasoning in certain kinds of timber.

Skating Rinks have for many years been provided with artificial surfaces of ice so that skating can be enjoyed at any season of the year. The ice surface is usually formed by laying a network of pipes over the floor of the rink, through which a strong solution of calcium chloride brine is kept in constant circulation. Over these pipes sufficient water is pumped in the first instance to form a thick coating of ice, which is carefully swept each night when skating is finished. Water is then distributed over the surface from a hose pipe, which quickly freezes into a perfect skating surface for use next day.

In several skating rinks the refrigerating installation has been also employed for the manufacture of ice and for cold storage chambers.

CHAPTER XII

THE FROZEN MEAT TRADE

OF all the directions in which refrigeration has proved its immense value there stands prominently in the foreground the assistance it has rendered to the food supply of the whole world, by making it possible to bring fresh meat from all parts of the earth, however distant. This has proved of supreme importance in two ways, to the sheep-farmer and cattle-raiser in providing a market for their previously wasted produce, and in furnishing a bountiful supply of excellent meat at moderate prices to nations unable to produce sufficient for their ever-increasing consumption. And if previous recognition of these immense advantages had not been sufficient, the way in which refrigeration supplied abundant and wholesome food for all the troops engaged in the Great War would alone have entitled it and its promoters to the world's everlasting gratitude and respect.

Prior to 1847 the sole outlet for the carcases of the sheep slaughtered in Australia and New Zealand for their wool, and the cattle slaughtered in Argentina for their hides, was "boiling down" for tallow. The result was that sheep were only worth about 3s. 6d. apiece and cattle from £2 to £4.

Canning was started about this time and proved acceptable, and for many years large quantities came to the United Kingdom selling readily at about 4d. or 5d. a pound, the British Admiralty being large purchasers.

Meanwhile various inventors were experimenting with the possibilities of freezing meat sufficiently hard to enable the carcase to be shipped across without resorting to canning. Amongst the pioneers were Carré, the eminent French chemist and engineer; James Harrison of Geelong; Charles Tellier, another French engineer who is justly claimed by his fellow-countrymen as a "father of refrigeration"; and Thomas Mort, intimately connected with the first successful shipment of frozen meat to this country. Mr. Mort started the first meat freezing works in the world at Darling Harbour, Sydney, in 1861 and spent much thought and a large fortune in preparing for the export trade which he foresaw was only a question of time and development. In 1876 he prepared a trial shipment to England in the sailing ship *Northam,* which was fitted with an ammonia compression plant similar to those used on land, but the machinery broke down before the vessel left harbour and the meat had to be discharged.

In 1876 Tellier installed three machines in *Le Frigorifique* and carried some meat from France to Buenos Aires, which arrived in sufficiently good condition to warrant bringing a return cargo of frozen meat to Rouen, which was also landed in sufficiently good condition, after a prolonged voyage of 110 days, to prove that the problem of carrying meat across the ocean under refrigeration had been solved. The first successful shipment of fresh meat to London was in 1880 by the *Strathleven* fitted with a Bell-Coleman cold air plant. This meat arrived in fine condition and sold readily at 4½d. to 5½d. for the beef and 5½d. to 6d. for the mutton. Since 1880 it has been a constant progress in successful shipments from Australia, New Zealand, South America and South Africa.

Meanwhile, in 1901, as the result of long experiments carried out by the River Plate Fresh Meat Co., chilled beef was shipped on a large scale and soon developed into a most successful business, the meat thus sent to London fetching most gratifying prices compared with frozen beef.

Complaints were, however, made from time to time of extensive and serious losses in chilled beef from mould spots, and this led to Mr. J. A. Linley experimenting with a sterilizing process, which he patented, and which has since been generally used in this trade, until superseded recently by a still more successful sterilizing agent, "Thymol," a vegetable product, whereas the first sterilizer, "Formaldehide," though harmless enough, was objected to by certain scientists and Government officials as being a chemical preservative. Under the Linley processes many thousands of carcases of beef have been brought over in perfect condition since the first commercial shipment in 1907 and bacon is now being brought over under similar treatment and with equal success. Whereas in the early eighties Great Britain, beyond a few experimental shipments to France, was the only market for frozen and chilled meat, and quite prepared to take all that was forthcoming, now other continental countries, France, Belgium, Switzerland, Italy, Germany and, lastly, Spain, have to increase their own sources of meat supply from beyond the seas in ever-growing quantities.

Little wonder then that the trade has increased to enormous figures, as shown by the table on next page, prepared from Messrs. Weddel & Co.'s last *Review of the Frozen Meat Trade*, for 1919, which shows the world's production of meat, frozen and chilled, and the total importation into the United Kingdom during the past seven years.

New Zealand farmers in particular found in the frozen meat trade a solution, at a critical time, for their difficulties in carrying on their industry on a paying basis, so that the colony at once proceeded to follow it up with regularity, resulting in steady progress and increased prosperity. In 1891 there were 17 freezing works in New Zealand, with a total freezing capacity of 3,665,000 sheep a year. In 1911 the number of works had increased to 31, with a daily capacity of 82,000 sheep and lambs, and in 1920 the number of works is 48, with a capacity of about 125,000 per day.

Year.	*Australian Output.*	*New Zealand Output.*	*Canadian Output.*	*South African Output.*	*South American Output.*	*U.S.A. & other Foreign Countries Output.*	*Total Output of the World.*	*Importations into United Kingdom.*	
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*Tons.*	*% of World Output*
1913	179,000	124,000	—	—	464,000	—	767,000	721,000	94
1914	171,000	147,000	—	—	478,000	5,000	801,000	694,000	87
1915	133,000	158,000	6,000	3,000	471,000	111,000	882,000	664,000	75
1916	104,000	158,000	15,000	8,000	535,000	96,000	916,000	534,000	58
1917	119,000	117,000	55,000	22,000	540,000	112,000	965,000	433,000	45
1918	67,000	99,000	46,000	8,000	690,000	220,000	1,130,000	489,000	43
1919	138,000	198,000	48,000	18,000	590,000	86,000	1,078,000	528,000	49

Whereas in Australia the stock is killed in many cases at some distance from the freezing works and has to be conveyed to them for freezing, in New Zealand and Argentina the invariable practice is to have the whole series of operations complete in one set of buildings. As soon as the carcases are " set " after killing, usually by being placed in a cooling room through which a constant current of cold air from the refrigerating plant is passed, they are conveyed by overhead rails to the freezing rooms, where they remain until they are hard frozen, ranging in time from 24 to 48 hours. As soon as the carcases are frozen thoroughly hard, bags are put on, with numbers corresponding to the tickets—indicating grade and quality—which have been affixed to the carcases when being graded. Immediately after bagging the carcases go into the storage chambers, where they are stacked up one on top of another, the various marks and numbers being kept separate until wanted for shipment. It was in these storage chambers that the practice of "telescoping" the carcase was introduced, the inability of the British Government to find shipping space during the War causing a conglomeration in the New Zealand stores which seems likely to extend well into the present year.

It was found that a considerable saving could be effected by cutting the carcase of a sheep or lamb in halves, and inserting one half in the other as far as it would go, a practice which also, of course, saved space in the hold of the vessel. But the practice was abandoned as soon as shipping space became normal, as meat salesmen strongly objected to these "cut" carcases, claiming that they were spoiled for cutting up by the retailer to the best advantage, and also were less attractive to the purchaser.

Every carcase of meat exported, from New Zealand most particularly, is subjected to the most rigid inspection by Government officials. Every possible care is taken in exporting countries to insure the meat being properly handled from the moment of slaughtering until it is placed in the vessel's hold. Extreme cleanliness is insisted on throughout ; care is taken to shield from exposure even during the rapid transit from the refrigerated van in which the meat is conveyed from the works to the shipside. Yet, on arrival in this country, studied indifference to all such matters seems the rule and not the exception. Dirty methods of handling, from which the bagging is not always sufficient to protect the carcase ; careless exposure to the sun's heat, or contaminations always present, while carting the meat through the streets on arrival in port of discharge, or up the river in barges ; conveying by rail in filthy, unrefrigerated wagons, or partially refrigerated wagons used for other traffic on the return journey ; carelessness in defrosting by the purchaser, and further exposure to contamination in the retailer's shop, are but a poor recognition of the extreme care taken on the other side, and justly arouse the indignation of colonials when brought under their notice.

Defrosting and thawing are important operations in connection with the proper treatment of frozen meat, to insure the best results to the consumer. The latter is apt to forget certain differences always existing between frozen and fresh meat. First of all comes the forgetting of the fact that a joint of frozen meat, on its arrival in this country, after the longest voyage, or when finally sold after coming out of cold storage, may be taken as generally equal to a joint of fresh meat some twelve hours after killing. It requires, therefore, a similar amount of hanging to become palatable. Again, if the meat as received from cold stores is not slowly and thoroughly thawed before cooking it is found to be hard when cooked, possibly discoloured, and forthwith condemned, in common with other imported meat ; whereas the chances are, had it been properly treated, it would have been pronounced, as it deserved to be, superior to the ordinary home-killed article, unless this was of the very best quality, not merely stated to be so !

When frozen meat is being thawed out under ordinary conditions the moisture from the air is apt to condense on the surface and thoroughly wet the meat, causing it to " weep " and become discoloured. Quarters of beef, with their great areas of exposed flesh, are particularly affected. The unsightly appearance of the meat is, however, the chief harm done. Retailers have their own methods of dealing with this difficulty, and they usually wipe off the moisture as it collects. Many mechanical means have been tried for artificially thawing or "defrosting" frozen beef more especially, warm, dry air being the usual medium employed, forced through a thawing chamber for a period of two to five days, with or without the aid of calcium chloride to assist absorbing moisture. The housekeeper, if she has reason to think that the meat she has purchased is not already properly thawed out by the retailer, will do well to give it time to completely thaw out before cooking, placing it for the purpose in a moderate temperature, assisting the process if time is an object by placing the meat in cold water, wiping, and then hanging, in the case of legs or shoulders of mutton or lamb, with the fleshy part uppermost.

Some idea of the immensity of the frozen meat industry at the present time may be gauged from the fact that the total quantities of frozen mutton and lamb imported into the United Kingdom during 1919 were 6,426,181 carcases of mutton and 3,482,219 carcases of lamb, as compared with a combined total of 400 carcases of mutton and lamb in 1880, and 2,948,076 in 1890.

This tremendous growth of the overseas meat trade, however, set another problem to be solved, that of storing the huge supplies coming into the United Kingdom ; and once again the question was solved, just as the industry itself was founded, by British enterprise and capital. The cold storage capacity of the principal stores available in London alone exceeds 13,000,000 cu.

ft., while the principal stores in the provinces have a capacity of nearly 22,000,000 cu. ft.

Without taking into account the very large numbers of provincial cold stores with a capacity of less than 100,000 cu. ft. each, which are not included in the above total, this 35,000,000 cu. ft. is equivalent to about 348,000 tons of meat, if stowed solid as on board ship. If stowed, however, in the ordinary way, with access allowed to various descriptions and marks, the estimated capacity would have to be reduced by nearly one-half.

APPENDIX

TABLES OF

TEMPERATURES, PROPERTIES, AND CAPACITIES

TEMPERATURES FOR THE COLD STORAGE OF VARIOUS ARTICLES

Articles.	*Deg. Fah.*	*Articles.*	*Deg. Fah.*
Beef (chilled)	32–33	Chestnuts	33
,, (frozen)	18–22	Dates, figs, etc.	55
Meat (canned)	35	Fruits (canned)	35
,, (fresh)	35–40	,, (dried)	35–40
Mutton (frozen)	18–22	Grapes	36–38
Rabbits (frozen)	18–22	Lemons	36–40
Game (frozen)	18–22	Nuts	35
Poultry (frozen)	18–22	Oranges	45–50
Butter (dairy)	34–38	Peaches	45–55
,, (imported)	18–22	Pears	35
Butterine (imported)	18–22	Plums	36–40
Cream	35	Watermelons	35
Milk	32	Asparagus	35
Oleomargarine	18–25	Beans (dried)	32–40
Cheese	36–40	Bulbs	33–35
Eggs	33–35	Cabbage	35
Fish (dried)	35	Carrots	35
,, (fresh)	25–30	Celery	35
Oysters	33–35	Cucumbers	38–40
,, (in tubs)	25	Flour	40
Sardines (canned)	35	Hops (with cool dry air)	38–40
Oil	35	,, (frozen)	28
Chocolate	40–45	Oatmeal	40
Honey	45	Onions	35–40
Sugar	40–45	Parsnips	35
Syrup	35	Peas (dried)	40
Beer (chilled for bottling)	28–30	Potatoes	36–40
,, (in bottle)	45	Sauerkraut	35–38
Cider	35–40	Seeds	35
Wines	45–50	Tomatoes	35
Apples	33–36	Cigars	35
Bananas	45–50	Tobacco	35
Berries (fresh)	36–40	Furs (undressed)	35
Cranberries	34–36	Furs, woollens, etc.	25–30
Canteloupes	40		

TEMPERATURES.—CENTIGRADE AND FAHRENHEIT.

° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.
109	228·2	71	159·8	33	91·4	— 5	23
108	226·4	70	158	32	89·6	— 6	21·2
107	224·6	69	156·2	31	87·8	— 7	19·4
106	222·8	68	154·4	30	86	— 8	17·6
105	221	67	152·6	29	84·2	— 9	15·8
104	219·2	66	150·8	28	82·4	— 10	14
103	217·4	65	149	27	80·6	— 11	12·2
102	215·6	64	147·2	26	78·8	— 12	10·4
101	213·8	63	145·4	25	77	— 13	8·6
100	212	62	143·6	24	75·2	— 14	6·8
99	210·2	61	141·8	23	73·4	— 15	5
98	208·4	60	140	22	71·6	— 16	3·2
97	206·6	59	138·2	21	69·8	— 17	1·4
96	204·8	58	136·4	20	68	— 18	— 0·4
95	203	57	134·6	19	66·2	— 19	— 2·2
94	201·2	56	132·8	18	64·4	— 20	— 4
93	199·4	55	131	17	62·6	— 21	— 5·8
92	197·6	54	129·2	16	60·8	— 22	— 7·6
91	195·8	53	127·4	15	59	— 23	— 9·4
90	194	52	125·6	14	57·2	— 24	— 11·2
89	192·2	51	123·8	13	55·4	— 25	— 13
88	190·4	50	122	12	53·6	— 26	— 14·8
87	188·6	49	120·2	11	51·8	— 27	— 16·6
86	186·8	48	118·4	10	50	— 28	— 18·4
85	185	47	116·6	9	48·2	— 29	— 20·2
84	183·2	46	114·8	8	46·4	— 30	— 22
83	181·4	45	113	7	44·6	— 31	— 23·8
82	179·6	44	111·2	6	42·8	— 32	— 25·6
81	177·8	43	109·4	5	41	— 33	— 27·4
80	176	42	107·6	4	39·2	— 34	— 29·2
79	174·2	41	105·8	3	37·4	— 35	— 31
78	172·4	40	104	2	35·6	— 36	— 32·8
77	170·6	39	102·2	1	33·8	— 37	— 34·6
76	168·8	38	100·4	0	32	— 38	— 36·4
75	167	37	98·6	— 1	30·2	— 39	— 38·2
74	165·2	36	96·8	— 2	28·4	— 40	— 40
73	163·4	35	95	— 3	26·6	— 41	— 41·8
72	161·6	34	93·2	— 4	24·8	— 42	— 43·6

FRACTIONAL EQUIVALENTS.

° C.	° F.	° C.	° F.
0·1	0·18	0·6	1·08
0·2	0·36	0·7	1·26
0·3	0·54	0·8	1·44
0·4	0·72	0·9	1·62
0·5	0·90	1·0	1·80

TEMPERATURES—FAHRENHEIT AND CENTIGRADE.

°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
330	165·6	267	130·6	206	96·7	143	61·7	80	26·7	19	—7·2
329	165	266	130	205	96·1	142	61·1	79	26·1	18	—7·8
328	164·4	265	129·4	204	95·6	141	60·6	78	25·6	17	—8·3
327	163·9	264	128·9	203	95	140	60	77	25	16	—8·9
326	163·3	263	128·3	202	94·4	139	59·4	76	24·4	15	—9·4
325	162·8	262	127·8	201	93·9	138	58·9	75	23·9	14	—10·
324	162·2	261	127·2	200	93·3	137	58·3	74	23·3	13	—10·6
323	161·7	260	126·7	199	92·8	136	57·8	73	22·8	12	—11·1
322	161·1	259	126·1	198	92·2	135	57·2	72	22·2	11	—11·7
321	160·6	258	125·6	197	91·7	134	56·7	71	21·7	10	—12·2
320	160	257	125	196	91·1	133	56·1	70	21·1	9	—12·8
319	159·4	256	124·4	195	90·6	132	55·6	69	20·6	8	—13·3
318	158·9	255	123·9	194	90	131	55	68	20	7	—13·9
317	158·3	254	123·3	193	89·4	130	54·4	67	19·4	6	—14·4
316	157·8	253	122·8	192	88·9	129	53·9	66	18·9	5	—15
315	157·2	252	122·2	191	88·3	128	53·3	65	18·3	4	—15·6
314	156·7	251	121·7	190	87·8	127	52·8	64	17·8	3	—16·1
313	156·1	250	121·1	189	87·2	126	52·2	63	17·2	2	—16·7
312	155·6	249	120·6	188	86·7	125	51·7	62	16·7	1	—17·2
311	155	248	120	187	86·1	124	51·1	61	16·1	0	—17·8
310	154·4	247	119·4	186	85·6	123	50·6	60	15·6	—1	—18·3
309	153·9	246	118·9	185	85	122	50	59	15	—2	—18·9
308	153·3	245	118·3	184	84·4	121	49·4	58	14·4	—3	—19·4
307	152·8	244	117·8	183	83·9	120	48·9	57	13·9	—4	—20
306	152·2	243	117·2	182	83·3	119	48·3	56	13·3	—5	—20·6
305	151·7	242	116·7	181	82·8	118	47·8	55	12·8	—6	—21·1
304	151·1	241	116·1	180	82·2	117	47·2	54	12·2	—7	—21·7
303	150·6	240	115·6	179	81·7	116	46·7	53	11·7	—8	—22·2
302	150	239	115	178	81·1	115	46·1	52	11·1	—9	—22·8
301	149·4	238	114·4	177	80·6	114	45·6	51	10·6	—10	—23·3
300	148·9	237	113·9	176	80	113	45	50	10	—11	—23·9
299	148·3	236	113·3	175	79·4	112	44·4	49	9·4	—12	—24·4
298	147·8	235	112·8	174	78·9	111	43·9	48	8·9	—13	—25
297	147·2	234	112·2	173	78·3	110	43·3	47	8·3	—14	—25·6
296	146·7	233	111·7	172	77·8	109	42·8	46	7·8	—15	—26·1
295	146·1	232	111·1	171	77·2	108	42·2	45	7·2	—16	—26·7
294	145·6	231	110·6	170	76·7	107	41·7	44	6·7	—17	—27·2
293	145	230	110	169	76·1	106	41·1	43	6·1	—18	—27·8
292	144·4	229	109·4	168	75·6	105	40·6	42	5·6	—19	—28·3
291	143·9	228	108·9	167	75	104	40	41	5	—20	—28·9
290	143·3	227	108·3	166	74·4	103	39·4	40	4·4	—21	—29·4
289	142·8	226	107·8	165	73·9	102	38·9	39	3·9	—22	—30
288	142·2	225	107·2	164	73·3	101	38·3	38	3·3	—23	—30·6
287	141·7	224	106·7	163	72·8	100	37·8	37	2·8	—24	—31·1
286	141·1	223	106·1	162	72·2	99	37·2	36	2·2	—25	—31·7
285	140·6	222	105·6	161	71·7	98	36·7	35	1·7	—26	—32·2
284	140	221	105	160	71·1	97	36·1	34	1·1	—27	—32·8
283	139·4	220	104·4	159	70·6	96	35·6	33	0·6	—28	—33·3
282	138·9	219	103·9	158	70	95	35			—29	—33·9
281	138·3	218	103·3	157	69·4	94	34·4	Water freezes.		—30	—34·4
280	137·8	217	102·8	156	68·9	93	33·9	32	0.	—31	—35
279	137·2	216	102·2	155	68·3	92	33·3	31	—0·6	—32	—35·6
278	136·7	215	101·7	154	67·8	91	32·8	30	—1·1	—33	—36·1
277	136·1	214	101·1	153	67·2	90	32·2	29	—1·7	—34	—36·7
276	135·6	213	100·6	152	66·7	89	31·7	28	—2·2	—35	—37·2
275	135			151	66·1	88	31·1	27	—2·8	—36	—37·8
274	134·4	Water boils.		150	65·6	87	30·6	26	—3·3	—37	—38·3
273	133·9	212	100.	149	65	86	30	25	—3·9	—38	—38·9
272	133·3	211	99·4	148	64·4	85	29·4	24	—4·4	—39	—39·4
271	132·8	210	98·9	147	63·9	84	28·9	23	—5	Mercury freezes.	
270	132·2	209	98·3	146	63·3	83	28·3	22	—5·6		
269	131·7	208	97·8	145	62·8	82	27·8	21	—6·1	—40	—40
268	131·1	207	97·2	144	62·2	81	27·2	20	—6·7		

THE PROPERTIES OF CALCIUM CHLORIDE BRINE, COMMERCIAL QUALITY (73 TO 75%).

Specific Gravity.	*Density in Degrees Twaddell at 60° Fahr.*	*Lb. per Cu. Foot of Solution.*	*Lb. per Gallon of Solution.*	*Freezing Point, Degrees, Fahr.*
1·100	20	10·70	1·72	18·5
1·125	25	13·47	2·16	13·3
1·150	30	16·26	2·61	7·5
1·175	35	19·15	3·07	0
1·200	40	22·05	3·54	— 8·7
1·225	45	25·06	4·02	— 19·5
1·250	50	28·06	4·50	— 32·6
1·261	52·2	30·00	4·81	— 30·3
1.272	54·4	31·30	5·02	— 46·2
1·283	56·6	32·70	5·25	— 54·4

THE SPECIFIC HEAT OF CALCIUM CHLORIDE BRINE.

Temp., Degrees Fahr.	38° *Twaddell at* 60° *F. Specific Gravity,* 1·19.		40° *Twaddell at* 60° *F. Specific Gravity,* 1·20.		42° *Twaddell at* 60° *F. Specific Gravity,* 1·21.	
	Specific Heat.	*B.T.U. per ° F. per Gallon.*	*Specific Heat.*	*B.T.U. per ° F. per Gallon.*	*Specific Heat.*	*B.T.U. per ° F. per Gallon.*
— 10	·699	8·32	·687	8·24	·676	8·18
0	·704	8·38	·692	8 31	·681	8·24
+ 10	·710	8·45	·698	8·37	·687	8·31
20	·715	8 51	·703	8·44	·692	8·37
30	·721	8·58	·709	8·51	·698	8·44
40	·726	8·64	·714	8·57	·703	8·51
50	·732	8·71	·720	8·64	·709	8·57
60	·737	8·77	·725	8·70	·714	8·64

TABLE SHOWING PROPERTIES OF SOLUTION OF SALT.

(Chloride of Sodium.)

Percentage of Salt by Weight.	*Pounds of Salt per Gallon of Solution.*	*Degrees on Salometer at 60° F.*	*Weight per Gallon at 39° F. = 4° C.*	*Specific Gravity at 39° F. = 4° C.*	*Specific Heat.*	*Freezing Point, Fahr.*	*Freezing Point, Celsius.*
1	·084	4	8·40	1·007	·992	30·5	— ·8
2	·169	8	8·46	1·015	·984	29·3	— 1·5
2·5	·212	10	8·50	1·019	·980	28·6	— 1·9
3	·256	12	8·53	1·023	·976	27·8	— 2·3
3·5	·300	14	8·56	1·026	·972	27·1	— 2·7
4	·344	16	8·59	1·030	·968	26·6	— 3·
5	·433	20	8·65	1·037	·960	25·2	— 3·8
6	·523	24	8·72	1·045	·946	23·9	— 4·5
7	·617	28	8·78	1·053	·932	22·5	— 5·3
8	·708	32	8·85	1·061	·919	21·2	— 6·
9	·802	36	8·91	1·068	·905	19·9	— 6·7
10	·897	40	8·97	1·076	·892	18·7	— 7·4
12	1·092	48	9·10	1·091	·874	16·	— 8·9
15	1·389	60	9·26	1·115	·855	12·2	—11·
20	1·928	80	9·64	1·155	·829	6·1	—14·4
24	2·376	96	9·90	1·187	·795	1·2	—17·1
25	2·488	100	9·97	1·196	·783	·5	—17·8
26	2·610	104	10·04	1·204	·771	—1·1	—18·4

TABLE OF FREEZING MIXTURES

Composition.	*Reduction of Temp. in Degrees Fahr.*		*Amt. of Fall in Degrees Fahr.*
	From.	*To.*	
Snow or pounded ice 2 parts, muriate of soda 1 part	—	— 5	—
Snow 5, muriate of sodium 2, muriate of ammonia 1	—	—12	—
Snow 24, muriate of sodium 10, muriate of ammonia 5, nitrate of potash 5	—	—18	—
Snow 12, muriate of sodium 5, nitrate of ammonia 5	—	—25	—
Snow 4, muriate of lime 5	+32	—40	72
Snow 1, chloride of sodium or common salt 1	+32	0	32
Snow 3, dilute sulphuric acid 2	+32	—23	55
Snow 3, hydrochloric acid 5	+32	—27	59
Snow 7, dilute nitric acid 4	+43	—30	62
Snow 8, chloride of calcium 5	+32	—40	72
Snow 3, potassium 4	+32	—51	83
Snow 2, dilute sulphuric acid 1, dilute nitric acid 1	—10	—56	46
Snow 12, common salt 5, nitrate of ammonia 5	—18	—25	7
Snow 1, muriate of lime 3	—40	—73	33
Snow 8, dilute sulphuric acid 10	—68	—91	23
Chloride of ammonia 5, nitrate of potassium, water 16	+50	+ 4	46
Nitrate of ammonia 1, water 1	+50	+ 4	46
Chloride of ammonia 1, nitrate of potassium 5, sulphate of sodium 8, water 16	+50	+ 4	46
Sulphate of sodium 5, dilute sulphuric acid 4	+50	+ 3	47
Sulphate of sodium 8, hydrochloric acid 9	+50	— 0	50
Nitrate of sodium 3, dilute nitric acid 2	+50	— 3	53
Nitrate of ammonia 1, carbonate of sodium 1, water 1	+50	— 7	57
Sulphate of sodium 6, chloride of ammonia 4, nitrate of potassium 2, dilute nitric acid 4	+50	—10	60
Phosphate of sodium 9, dilute nitric acid 4	+50	—12	62
Sulphate of sodium 6, nitrate of ammonia 5, dilute nitric acid 4	+50	—14	64
Phosphate of sodium 5, nitrate of ammonia 3, dilute nitric acid 4	0	—34	34
Phosphate of sodium 3, nitrate of ammonia 2, dilute mixed acid 4	— 34	—50	16
Snow 3, muriate of lime 4	+ 20	— 48	68
Snow 1, muriate of lime crystallised 2	0	—66	66
Snow 2, muriate of lime 3	—15	—68	53
Snow 8, dilute sulphuric acid 3, dilute nitric acid 3	—10	—56	46
Snow 3, dilute nitric acid 2	0	—46	46
Snow 1, dilute sulphuric acid 1	—20	—60	40
Snow 2, muriate of lime crystallized 3	—40	—73	33
Snow 8, dilute sulphuric acid 10	—68	—91	23

FREEZING TIMES FOR DIFFERENT TEMPERATURES AND THICKNESSES OF CAN ICE

(*From the "Compend of Mechanical Refrigeration."*)

Thickness.	1 *in.*	2 *in.*	3 *in*	4 *in.*	5 *in.*	6 *in.*	7 *in.*	8 *in.*	9 *in.*	10 *in.*	11 *in.*	12 *in.*
Temperature 10°	·32	1·28	2·86	5·10	8·	11·5	15·6	20·4	25·8	31·8	38·5	45·8
" 12°	·35	1 40	3·15	5·60	8·75	12·6	17·3	22·4	28·4	35·	42·3	50·4
" 14°	·39	1·56	3·50	6·22	9·70	14·	19·	25·	31·5	39·	47·	56·
" 16°	·44	1·75	3·94	7.	11·	15·8	21·5	28·	35·5	43·7	53·	63·
" 18°	·50	2.	4·50	8·	12·5	18·	24·5	32·	40·5	50·	60·5	72·
" 20°	·58	2·32	5·25	9 30	14·6	21·	28·5	37·3	47·2	58·3	70·5	84·
" 22°	·70	2·80	6.30	11·2	17·5	25·2	34·3	44·8	56·7	70·	84·7	100·
" 24°	·88	3·50	7·86	14·	21·	31·5	42·8	56·	71·	87·5	106·	125·

DIMENSIONS OF ICE-MAKING TANKS.

Table compiled by Skinkle, giving sizes of some freezing tanks, piping, and moulds in actual operation.

(*From the "Compend of Mechanical Refrigeration."*)

Tons Ice-making Capacity	*No. of Tanks.*	*Sizes of Tanks.*				*No. of Coils.*	*Size of Pipe.*	*No. of Pipes High.*	*Length of Coils.*	*Total Ft. of Pipe in Tank.*	*Ft. per Pipe per Ton Ice-making Capacity.*	*No. of Ice Moulds in Tank.*	*Size of Moulds.*	*Nett Weight of Ice from each Mould.*	*No of Moulds per Ton Ice-making Capacity.*	*No. of Hours for Freezing each Mould.*	*Remarks.*
		Length of Tank.	*Width of Tank.*	*Depth of Tank.*	*Thickness of Plates.*												
		ft. in.	*ft.* in.	*in.*	*in.*		*in.*						*Inches.*	*lbs.*			
1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	1	17 0	6 2	33	$\frac{3}{16}$	7	1	6	15 4	644	322	60	8 × 15 × 33	100	30	36	–
3	1	17 0	9 0	33	$\frac{3}{16}$	10	1	6	15 0	900	300	90	8 × 15 × 33	100	30	36	–
5	1	17 0	14 9	33	$\frac{3}{16}$	16	1	6	15 0	1,440	288	150	8 × 15 × 33	100	30	36	–
10	1	29 0	19 0	33	¼	25	1	8	17 0	3,400	340	192 24	11 × 22 × 33 11 × 11 × 33	200 100	20·4	48	–
12½	1	37 6	19 0	33	¼	33	1	8	17 0	4,488	329	256 32	11 × 22 × 33 11 × 11 × 22	200 100	21·36	52·2	Special
15	1	43 0	19 0	33	¼	37	1	8	17 0	5,032	335	288 36	11 × 22 × 33 11 × 11 × 33	200 100	20·4	48	–
20	2	29 0	19 0	33	¼	25	1	8	17 0	3,400	340	192 24	11 × 22 × 33 11 × 11 × 33	200 100	20·4	48	(*
30	2	43 0	19 0	33	¼	37	1	8	17 0	5,032	335	288 36	11 × 22 × 33 11 × 11 × 33	200 100	20·4	48	(*)
30	1	43 0	30 0	48	¼	35	1¼	8	28 0	7,840	261	480	11 × 22 × 45	300	16	57·6	–
60	2	56 0	20 0	48	¼	49	1¼	10	18 0	8,820	294	432	11 × 22 × 45	300	14·4	51·8	–
60	2	43 0	30 0	48	¼	35	1¼	8	28 0	7,840	261	480	11 × 22 × 45	300	16	57·6	(*)

Average of 1 in. pipe per ton, 327 ft. Average of 1¼ in. pipe per ton, 272 ft.

(*) 20-ton tanks are duplicate 10-ton tanks
30-ton „ „ 15-ton „
60-ton 30-ton „
} Dimensions of one tank only are given in each instance.

DIMENSIONS OF CONDENSERS:

The following tables, compiled by Skinkle, give the dimensions of both submerged and atmospheric condensers of some plants in actual operation, and allow much more pipe for the atmospheric than for the submerged condenser :

ATMOSPHERIC CONDENSERS.

Ice-making Capacity in Tons.	Refrigerating Capacity in Tons.	*Condenser Pans.* Length of Pan in Feet.	Width of Pan in Feet.	Depth of Pan in Ins.	Thickness of Iron in Ins.	No. of Pipes High.	No. of Pipes Wide.	Size of Pipe in Inches.	Length of Coil over Bends in Ft.	Total Feet of Pipe in Condenser.	Feet of Pipe per Ton, Ice-making Capacity.	Feet of Pipe per Ton, Refrigerating Capacity.
12½	25	21	10⅝	8	3/16	40	5	1	17	3,680	294·4	147·2
20	35	24½	10⅝	8	3/16	40	5	1	21	4,440	222·	126·8
30	50	24½	14	8	3/16	50	7	1	21	7 750	258·3	155·
40	75	24½	14	8	3/16	50	7	1¼	21	7 750	193·75	103·33
50	100	24½	14	8	3/16	90	7	1	21	13,950	279·	139·5
60	125	24½	14	12	3/16	80	7	1¼	21	12,400	206·6	99·2
80	150	27½	17	12	3/16	80	7	1¼	24	14,080	176·	93·86
						Avera	ge for	1in. p	ipe per	ton	263·42	142·12
						Avera	ge for	1¼in. p	ipe per	ton	192·12	98·79

SUBMERGED CONDENSERS.

Ice-making Capacity in Tons.	Refrigerating Capacity in Tons.	*Tanks.* Length in Feet.	Width in Feet.	Depth in Feet.	Thickness of Iron in Ins.	No. of Coils.	Pipes High.	Feet Long.	Size of Pipe in Inches.	Total Feet of Pipe in Condenser.	Feet of Pipe per Ton, Ice-making Capacity.	Feet of Pipe per Ton, Refrigerating Capacity.
5	10	10	3½	6½	3/16	9	12	7½	1	855	171·	85·5
10	20	10	7½	6½	3/16	20	12	7½	1	1,900	190·	95·
12½	25	10	7½	6½	3/16	22	12	7½	1	2,090	167·	83·6
15	30	10	8½	6½	3/16	25	12	7½	1	2,375	151·6	79·16
20	35	10	10	6½	3/16	27	12	7½	1	2,565	128 25	73·28
30	50	10	10	12½	¼	27	24	7½	1	5,130	171·	102·6
40	75	14	10	13½	⅜	27	24	11½	1	7,695	191·1	102·6
60	110	14	13	13½	⅜	35	24	11½	1	9.975	166·25	90·68
									Avera	ge	167·	89·

STRENGTH OF ICE.

Ice of a thickness of 1½ in. will support a man ; 4 ins. in thickness will support cavalry ; 5 ins. in thickness will support an 84 lb. cannon ; 10 in. in thickness will support a large body of men ; 18 ins. in thickness will support a railway train.

TABLE SHOWING REFRIGERATING EFFECT OF ONE CUBIC FOOT OF AMMONIA GAS AT DIFFERENT CONDENSER AND SUCTION (BACK) PRESSURE IN B.T. UNITS.

(*From the "Compend of Mechanical Refrigeration.*")

Temperature of Gas in Degrees F.	*Corresponding Suction Pressure lbs. per sq. in.*	*Temperature of the Liquid in Degrees F.*								
		65	70	75	80	85	90	95	100	105
		Corresponding Condenser Pressure (Gauge) lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	27·30	27·01	26·73	26·44	26·16	25·87	25·59	25·30	25·02
—20	4	33·74	33·40	33·4	32·70	32·34	31·99	31·64	31·30	30·94
—15	6	36·36	36·48	36·10	35·72	35·34	34·96	34·58	34·20	33·82
—10	9	42·28	41·84	41·41	40·97	40·54	40·10	39·67	39·23	38·80
— 5	13	48·31	47·81	47·32	46·82	46·33	45·83	45·34	44·84	44·35
0	16	54·88	54·32	53·76	53·20	52·64	52·08	51·52	50·96	50·40
5	20	61·50	60·87	60·25	59·62	59·	58·37	57·75	57·12	56·50
10	24	68·66	67·97	67·27	66·58	65·88	65·19	64·49	63·80	63·10
15	28	75·88	75·12	74·35	73·59	72·82	72·06	71·29	70·53	69·76
20	33	85·15	84·30	83·44	82·59	81·73	80·88	80·02	79·17	78·31
25	39	95·50	94·54	93·59	92·63	91·68	90·72	89·97	88·81	87·86
30	45	106·21	105·15	104·09	103·03	101·97	100·91	99·85	98·79	97·73
35	51	115·69	114·54	123·39	112·24	111·09	109·94	108·79	107·64	106·49

TABLE GIVING NUMBER OF CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES TO PRODUCE 1 TON OF REFRIGERATION IN TWENTY-FOUR HOURS.

(*From the "Compend of Mechanical Refrigeration.*")

Temperature of Gas in Degrees F.	*Corresponding Suction Pressure lbs. per sq. in.*	*Temperature of the Gas in Degrees F.*								
		63	70	75	80	85	90	95	100	105
		Corresponding Condenser Pressure (Gauge) lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	7·22	7 3	7·37	7·46	7·54	7·62	7·70	7·79	7·88
—20	4	5·84	5·9	5·96	6·03	6·09	6·16	6·23	6·30	6·43
—15	6	5·35	5·4	5·46	5·52	5·58	5·64	5·70	5·77	5·83
—10	9	4·66	4·73	4·76	4·81	4·86	4·91	4·97	5·05	5·08
— 5	13	4·09	4·12	4·17	4·21	4·25	4·30	4·35	4·40	4·44
0	16	3·59	3·63	3·66	3·70	3·74	3·78	3·83	3·87	3·91
5	20	3·20	3·24	3·27	3·30	3·34	3·38	3·41	3·45	3·49
10	24	2·87	2·9	2·93	2·96	2·99	3·02	3·06	3·09	3·12
15	28	2·59	2·61	2·65	2·68	2·71	2·73	2·76	2·80	2·82
20	33	2·31	2·34	2·36	2·38	2·41	2·44	2·46	2·49	2·51
25	39	2·06	2·08	2·10	2·12	2·15	2·17	2·20	2·22	2·24
30	45	1·85	1·87	1·89	1·91	1·93	1·95	1·97	2·	2·01
35	51	1·70	1·72	1·74	1·76	1·77	1·79	1·81	1·83	1·85

REFRIGERATING CAPACITY IN B.T.U. REQUIRED PER CUBIC FOOT TO STORAGE ROOM IN TWENTY-FOUR HOURS.

Size of Building in Cubic Feet more or less.	*Insulation.*	*Temperature Degrees Fahr.*					
		0	10	20	30	40	50
100	excellent	1,800	480	360	284	180	95
	poor	4,000	960	480	470	330	140
1,000	excellent	550	110	95	70	47	24
	poor	1,100	190	165	110	55	28
10,000	excellent	400	95	70	47	30	16
	poor	900	160	110	81	40	20
30,000	excellent	280	55	47	35	22	11
	poor	550	95	81	55	26	14
100,000	excellent	190	38	30	20	14	7
	poor	350	63	55	35	18	4

NUMBER OF CUBIC FEET COVERED BY 1 TON REFRIGERATING CAPACITY FOR TWENTY-FOUR HOURS

Size of Building in Cubic Feet more or less.	*Insulation.*	*Temperature Degrees Fahr.*					
		0	10	20	30	40	50
100	excellent	150	600	800	1,000	1,600	3,000
	poor	70	300	400	600	900	2,000
1,000	excellent	500	2,500	3,000	4,000	6,000	12,000
	poor	250	1,500	1,800	2,500	5,000	10,000
10,000	excellent	700	3,000	4,000	6,000	9,000	18,000
	poor	300	1,800	2,500	3,500	7,000	14,000
30,000	excellent	1,000	5,000	6,000	8,000	13,000	25,000
	poor	500	3,000	3,500	5,000	11,000	20,000
100,000	excellent	1,500	7,500	9,000	14,000	20,000	40,000
	poor	800	4,500	5,000	8,000	16,000	35,000

COMPARISON OF CALORIES AND BRITISH THERMAL UNITS.

The heat unit based on the centigrade or Celsius scale represents the amount of heat required to raise one kilogramme of water from 0° to 1° C. This is known as a "calorie." The British thermal unit represents the amount of heat required to raise one pound of water from 32° to 33° F.

Calories.	*British Thermal Units.*	*Calories.*	*British Thermal Units.*
1	3·96	60	236·16
2	7·92	70	276·12
3	11·88	75	297·
4	15·84	80	316·8
5	19·8	90	356·4
6	23·76	100	396·
7	27·72	125	495·
8	31·68	150	594·
9	35·64	175	693·
10	39·6	200	792·
15	59·4	250	990·
20	79·2	300	1188·
25	99·	400	1584·
30	118·8	500	1980·
40	158·4	750	2970·
50	198·	1000	3960·

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